1-1-1992

Optimal young sire usage for genetic improvement of dairy cattle

Abdul Hussain Nizamani
Iowa State University

Optimal young sire usage for genetic improvement
of dairy cattle

by

Abdul Hussain Nizamani

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Department: Animal Science
Major: Animal Breeding

Iowa State University
Ames, Iowa
1992

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The task for an animal breeder is to design selection programs, and to compare methods of genetic selection with the goal of optimizing genetic gain for specific situations and traits. Another important duty is to monitor genetic progress to determine whether gain that has been made can be increased.

Dairy cattle are the major source of milk throughout the world. The productive traits, such as milk yield, are quantitative in nature, and the expression of these traits requires the combination of large numbers of genes. On the other hand, these characters are significantly affected by environmental factors for their expression. Therefore, selection of these traits requires reliable methods, so that required genetic gain can be obtained within a limited time period.

Selection of males is more important than females in dairy cattle breeding programs, because males transmit their characteristics to a larger number of their descendents than females. But, the dairy characters are expressed only in females. Therefore, selection of young bulls for sex-limited traits requires selection by pedigree or some type of indirect selection (Freeman, 1975).

Pedigree selection for milk, fat, and protein yield was probably the most widely used method before artificial insemination (AI). But, after the introduction of AI, the need for progeny testing increased. Burnside (1974), reported that for progeny testing increased. Burnside (1974), reported that animal breeders were prepared to accept slightly lowered selection intensity on pedigree potential for milk yield or to pay a higher price to sample young dairy bulls. Henderson (1964) outlined many principles in selecting young sires to sample in AI. For AI bulls, progeny tests may be necessary to increase the accuracy of evaluation.

Maximizing the rate of genetic gain is the objective for animal breeders. Rendel and Robertson (1950) suggested that an annual gain of up to 2% of the mean is possible. The rapid genetic gain can be achieved by selecting and sampling young bulls, because the very best genetic material will be found among the young animals. As genetic progress accelerates, the importance of young animals in breeding programs increases. Making the most genetic progress possible requires a wise combination of four building blocks for rapid genetic change. The building blocks are selection intensity, accuracy, additive genetic standard deviation, and generation interval.

If selection intensity is increased for particular traits, it will result in an increase of generation interval. Achieving 2% of annual genetic gain requires intense and accurate selection of animals to use as parents of sires and dams while minimizing generation interval (Rendel and Robertson, 1950).

Accuracy is much lower for sample sires than it is for established proven bulls. However, young sires are younger and may have received superior genes, if the pedigree record is used wisely. We have to compensate for the lower accuracy by using a wider assortment of young sires with limited use of any one young sire. This reduces risk that one herd would have too many daughters of a young sire that turned out to be genetically inferior.

To predict the genetic progress of current Jersey herds we would like to evaluate the predicted difference between young selected individuals and all cows. Average weighted and unweighted predicted transmitting ability (PTA) for four paths of selection (i.e. dams of bulls, dams of cows, sires of bulls, and sires of cows) were compared with average PTA of all cows born in the same year. The increase in terms of monetary returns in current herds is shown by the genetic progress, obtained through sampling of A.I. bulls.

The purpose of this study was to assess the intensity and efficiency of selection in choosing young bulls to sample and in selecting proven bulls returned to extensive AI use. Also, the objective of this study was to monitor the selection practiced and genetic progress achieved in the past.

REVIEW OF LITERATURE

Pedigree prediction

Accuracy of pedigree information in predicting bulls progeny yield was examined by Norman and Powell (1986). They reported that the estimated transmitting ability of sires was a more useful predictor than that of dams or maternal grandsires. An index that combined sire, dam, and maternal grandsire information was the best predictor for Holsteins and Jerseys.

Pedigree evaluation and selection of young sires to progeny test, is probably the weakest point in dairy cattle improvement. This was reported by Van Vleck and Carter (1972). They also reported in the same study that any increase in the accuracy of pedigree evaluation could result in faster progress and/or less cost.

Butcher (1973) evaluated results of selection procedures in dairy cattle. He looked at the value of sire's progeny, dam, and maternal grandsire to predict son's breeding values from pedigree information and compared this expected breeding value with predicted difference (PD). The latter were stratified by sons entering AI at less than 37 months of age, all other AI sires, and non-AI sires. Sires entering AI at < 37 months had highest expected and observed correlations between son's index and proof, the next highest correlation was for all other AI bulls followed by non-AI sires. Generally expected correlations agreed well with observed.

Van Vleck (1969) stated that selection by using a pedigree should be based on a sire's proof, dams records, and the proof of the maternal grandsire (MGS). He found that this combination was the most effective one, but it was only 84% as efficient as a set of all relatives.

Butcher and Legates (1976) used pedigree information on 340 sons which entered AI as young bulls to study the use of three-point pedigree information (i.e. sire, dam, and MGS) to predict a son's actual transmitting ability. They found correlations of 0.47 between son and sire, 0.24 between son and MGS and 0.21, 0.16, 0.16, 0.08, and 0.08 between son and dam's first five lactations, respectively.

Vinson and Freeman (1972) examined pedigree selection achieved in choosing young Holstein bulls for future use in AI. The bulls and cows chosen to produce sons for sampling represented a group of individuals highly selected for milk and fat yield, pedigree selection, however, was less effective than expected.

Van Vleck (1982) derived theoretical weights for prediction of son's genetic evaluation from genetic evaluation of his sire and dam. Weights for sire and dam are equal and depend on number of daughters of son when the bull evaluation is from his daughters alone and cow evaluation is from her records alone. When records of daughters of both the son and his sire are used in evaluations of both, theoretical weights for the sire to predict the son's evaluation are about .5 for many combinations of daughter numbers of the bulls. Including the evaluation of the sire of the cow in her evaluation changes the theoretical weight to predict the son's evaluation from the dam's evaluation only slightly from the situation when only the dam's records are use. In addition, the theoretical weight for the maternal grandsire is nearly zero.

McGraw et al. (1980) studied 109,589 Holstein records from three AI stud's young sire sampling programs to compare performance. The 315 young bulls were sired by 88 sires. For young sires, pedigree index of sire, dam, and maternal grandsire averaged 347 kg milk and 11.8 kg fat, and for an index including sire and maternal grandsire averaged 242 kg milk and 7.6 kg fat.

Polyanichko (1981) found that selection for milk yield on cows own performance was 5 to 6 times more effective than selection on ancestor performance.

The maximum genetic progress is not economically feasible, so, some practical optimum is chosen arbitrarily. This was reported by Freeman (1974). He explained that expected gains through selection by pedigree can be estimated as direct response.

Progeny testing and rate of selection

Vinson and Freeman (1972) examined performance data supplied by seven major artificial insemination (AI) studs in the United States to evaluate the intensity of progeny test selection achieved in choosing young Holstein bulls for future use in AI. The studs returned to service approximately 25% of sons sampled. The mean performance of sons returned to service exceeded the mean performance of all sons sampled by 146.2 kg and 5.0 kg for regressed deviated milk and milk fat yield. Genetic progress per year might be considerably reduced by an excessively long generation interval.

Oltenacu and Young (1974) examined several alternatives for increasing rate of selection among progeny tested bulls by using a simulation model for AI populations. They reported that the rate of selection among progeny tested bulls could be increased profitably to 1 in 5 by breeding 12 to 35% of cows to young bulls, and to 1 in 9 by decreasing progeny group size from 150 to 50.

Mao et al. (1991) compared young bulls for AI sampling and progeny testing herds with their contemporary DHI herds. Herds in which young bulls were sampled had greater average milk production, greater variance for milk production, and greater genetic variance than other herd groups. Herds participating in progeny testing of young bulls were by far the most superior group.

An optimum progeny group size was 30 tested daughters per young bull sampled. Forty percent of the tested cows should be breed to young bulls when 20% of the cow population is milk recorded. These results were presented by Hunt et. al. (1972) in a simulation study on sire selection and sampling.

Legates (1970) reported results of sampling young sires based on pedigree selection in Holstein herds. He found that the herd-mate difference for daughters of the selected sires averaged 595 lb of milk above that for daughters of all young sires.

Lohuis et al. (1992) used probability theory to predict the probability of young AI sires achieving a successful progeny test evaluation and to predict their present value of net returns. Based on estimated breeding values with an accuracy of .6, young bulls from the 95th percentile were 11.7 and 6.3 times more likely to enter the top 5% (sires of bulls) and top 15% (sires of cows) of progeny tested sires than a young bull from the 5th percentile.

Gruter (1981) compared breeding values for milk yield of Brown Swiss sires which had at least 3 progeny-tested sons. For sires with breeding values greater than or equal to 50 kg, 54% of their sons also had a plus value (average, +53 kg); for sires with breeding values ranging from -49 kg to +49 kg, 36% of their sons had a plus value, but the average breeding value of sons was -113 kg; for sires with a breeding value of less than or equal to 50 kg, 28% of their sons had a plus value, and the average breeding value was -103 kg. Two bulls with breeding values of +1347 kg and +1252 kg left at least 10 progeny-tested sons each, all of which had greater than average breeding values.

Genetic gain and number of young sires sampled

Hunt et al. (1972) simulated annual genetic gain for milk yield for an AI population of 115,000 dairy cows for different values of nine variables in young sire selection and sampling, and proving stud operation. Maximum genetic advance required sampling a large number of young bulls annually (i.e., 34, 51, or 68 as compare to 17). Increasing selection intensity for dams of bulls averaging 1.0 to 2.5 standard deviation units above breed average yielded uniform increases in rate of genetic progress. Decreasing the number of bulls to sire young bulls to two or three each year and replacing one of these annually increased rates of genetic gain.

Goddard and Smith (1990) worked on optimization of the number of bull sires in dairy cattle breeding. They reported that for a given number of bulls tested per generation, the net response rises as the number of bull sires selected increases but soon reaches a maximum. As the number of generations in evaluation increases, the number of bull sires selected per generation increases. Compared with 5 generations (25 yr), the numbers of bull sires for a 20-generation period

(100 yr) are increased by a factor about 1.0 to 1.6. The optimization also indicates a considerable range in the number of bull sires selected that will give high proportions of the maximum response. For example, 8 to 12 bull sires per generation would give net responses greater than 95% of the maximum in all situations except when the number of bulls tested per generation is very low. They also observed that the accuracy of progeny test has very little effect on the optimum number of bull sires. For progeny testing systems, a conservative recommendation of a minimum effective number of 10 bull sires per generation for the whole breed is made, as this will allow both high genetic and high net genetic responses and will allay concern about inbreeding.

Hunt et al. (1974) in a simulation study reported a constant decrease in rate of genetic change as the number of sires of young bulls increased from two through eight for different population sizes when selection focussed on milk yield with 20% of the population milk recorded. Increases in the percent of cows bred to young bulls enhanced rates of genetic progress with greater increases in smaller populations. Genetic progress per year actually declined when the percent bred to young bulls reached 80%, with 80% percent of the population milk recorded in populations of 50,000 cows or greater. When population size is small (15,000 cows), genetic gain is maximized by sampling a larger number of young bulls with the smallest number of tested daughters per bull (e.g. 20 cows per bull). Accuracy is more than offset by increases in the selection differential among progeny tested bulls. In contrast, AI studs serving 750,000 cows or more will maximize genetic gains by sampling young bulls to obtain 40 to 60 tested daughters each. The 750,000 cow stud will also have reduced costs of housing, because fewer bulls are entering annually. As emphasis is placed on other traits in addition to milk, smaller progeny group sizes lead to an increase in the number of young bulls sampled and more rapid genetic progress. They concluded that many more young bulls could and should be sampled to approach maximum genetic progress for milk production.

Oltenacu and Young (1974) worked on optimization of a young bull sampling program in dairy cattle. They used an approach of maximization of genetic improvement per generation. Their results indicated that 100 young bulls should be progeny tested every year with 23 daughters per progeny group and 5 top bulls selected for use as proven sires. Also, 20% of the cow population should be used for sampling young sires. Of course, it may not be economically feasible to progeny test 100 young bulls per year in all populations. Therefore, less than optimum genetic improvement must be expected.

Dickerson and Hazel (1944) pointed out that the genetic improvement must be judged per year rather than per generation. They conclude that when breeding is considered for butterfat production in dairy cattle in a closed herd of 120 cows, the genetic improvement would actually be faster without progeny testing.

Norman and Powell (1986) examined the growth of the artificial insemination (AI) sampling program in the United States and changes in genetic merit of bulls that enter AI. Estimated transmitting ability of AI-sampled bulls increased 60 kg/year from 1980 to 1983. Combined increases in the number and genetic merit of AI sampled bulls should bring the annual rate of genetic improvement to over 1.5 % of the mean milk yield per year (presently at 1 %).

Jain and Jain (1981) compared the effect on genetic gain within crossbred dairy herds: i) on the performance of female progeny, ii) on the performance of sire and dam, or iii) on dam's yield alone. Herds of 300 and 600 cows with a progeny testing scheme with 1 tested sire and 6 to 8, and 7 to 10 young bulls, respectively, gave the highest annual genetic gain at 1.49 and 1.73% of the mean compared with 1.13 to 1.18% and 1.24 to 1.30% for bulls of best dams. However, for long term improvement the use of 2 tested bulls per cycle and 7 to 8 or 10 young bulls were recommended for herds of the two sizes, respectively.

Genetic gain from average selection differential and generation interval

Optimum genetic gain from AI can be obtained by evaluating sire-son generation intervals and selection differentials. Miller (1961) studied sire-son pairs to assess the amount of selection practiced in choosing bulls for service. The number of Jersey sire-son pairs was 2,590. The mean weighted selection differential for PD milk was +13 kg. Selection differentials for fat percentage were uniformly positive ranging from .03% to .05%.

Lytton (1969) studied all pairs of sires and their AI sons with predicted difference (PD) data to determine the degree of selection practiced in choosing bulls for use in AI. The number of Jersey AI sire-son pairs was 447. The selection differentials were generally positive for fat yield (0 to 2 kg), and fat percentage (-0.01 to .10%).

In a study of a 2,000 cow population under artificial insemination (AI), Robertson and Rendel (1950) reported theoretical genetic gain of 43% from sires of bulls, 33% from dams of bulls, 18% from sires of cows and 6% from dams of cows. They found that 76% of the theoretical gain could be expected from matings which produce young sires to be progeny tested. In another study, Skjervold (1963) reported theoretical genetic gains of 46%, 24%, 24%, and 6%, from the same four sources, respectively, for a 60,000 cow population under AI.

Hintz (1978) reported rates of genetic improvement/year in milk yield of 25.4, 26.1, and 25.0 kg, respectively, for Guernsey, Holstein, and Jersey AI cows. Trends in transmitting ability of AI sires for the Ayrshire, Guernsey, Holstein, Jersey, and Brown Swiss breeds were 23.7, 14.6, 17.9, 18.3, and 34.7 kg.

Van Tassell and Van Vleck (1991) calculated annual genetic gain in milk yield for the northeast United States by using weighted averages of selection differentials for parents of registered cows. The genetic gain was 34.9 kg/year, however, in the most recent 5 years the amount of genetic gain was 57.2 kg/year, which was only 57% of the optimum gain. The overall change for all cows, registered and grade, was considerably smaller at 18.7 kg/year.

Van Tassel and Van Vleck (1991) used estimated genetic values from an animal model based on first lactation milk records for 6,000 AI Holstein sires and 1,074,971 Holstein cows born in 1981 or before to calculate average genetic selection differentials for the four paths of selection for each year of birth. Selection differentials for paths of sires of bulls, dams of bulls, sires of cows, and dams of cows averaged over all years were 405, 395, 239, and 42 kg, respectively. Genetic selection differentials for the most recent 5 yr. were 884, 598, 235, and 28 kg. The average age of parents when their progeny were born, or generation intervals, were also calculated for the same animals as the genetic selection differentials. Generation intervals averaged over all years by path were 10.2, 6.4, 9.3, and 5.1 yr and for the most recent 5 yr they were 11.0, 6.4, 8.9, and 4.9 yr.

Rendel and Robertson (1950) suggested that annual genetic gains of up to 2% of the mean are possible. Achieving this goal requires intense and accurate selection of animals to use as parents of sires and dams while minimizing generation intervals. In another study, Burnside and Kuersten (1985) stressed the importance of reducing the generation intervals for the dams of bulls and sires of bulls paths to 6.0 and 7.0 years. They found that Canadian bull studs with bull crops entering in 1976 to 1977 had an average generation interval of 7.5 and 11.7 yr for these paths. By 1983 to 1984 the generation interval for the dams of bulls path had not changed much, 7.6 yr, but the generation interval for the sires of bulls path had been reduced to 9.0 yr.

In a study on first lactation records of AI Holsteins, Westell (1984) reported generation intervals of 4.86, 6.88, 8.47 and 9.73 yr, respectively, for the dams of cows, dams of bulls, sires of cows, and sires of bulls paths. The averages were of individual generation intervals rounded down to the nearest whole year so the sum of 29.94 years is an underestimate.

Lee et al. (1985) reported trends in average ages of sires and dams at the time of birth of their registered Holstein offspring for the four paths from 1960 to 1979. These averages may over or underestimate intervals for replacement animals. The averages also may be more representative for the dams of bulls and sires of bulls paths from a natural service than an AI population because the 440,702 males included all males born in the period. The intervals at the beginning and at the end of the time period were about 57 and 56 months for dams of cows, 68 and 66 months for dams of bulls, 78 and 90 months for sires of cows, and 77 and 109 months for sires of bulls.

McGraw (1980) used 109,589 records from cows in 1978 Holstein herds to compare performance in young sire sampling programs for three AI studs. Selection differentials from the top 15% sires, 1% dams, and 25% of maternal grandsires were 350, 2735, and 268 kg, respectively, when the young sires entered sampling programs. The 315 young bulls were sired by 88 sires.

<u>Alternative progeny testing schemes and risk of varying level of young sire usage</u>

Schneeberger et al. (1982) worked on evaluation of income and risk in selecting sires for artificial ansemination. For average transmitting ability (TA) of old bulls equal to young bulls, expected income increased with increasing proportions of young bulls used (p), when semen price for old bulls was larger than that for young bulls . For average TA of old bulls greater than young bulls, expected income decreased with increasing proportions of young bulls, when average transmitting ability was less than or equal to $100. For higher mean TA of young bulls , it was always more profitable to use young bulls because the higher semen costs for old bulls offset the difference in TA. When mean TA of old bulls was less than mean TA young of bulls, expected income increased with increasing proportions of young bulls in all cases. Increasing accuracy (Ro) means increasing semen prices for proven bulls and reduces expected income.

Risk does not depend on mean TA of old bulls and mean TA of young bulls. Income does. Increasing the proportion of young bulls increases risk because of lower repeatability of young bulls. Increasing repeatability of old bulls reduces risk. Using more bulls in the herds also reduces risk. The number of bulls, N, is limited by herd size; the maximum number of bulls to be used in a herd equals the number of heifers and cows in that herd. Risk is smallest when each cow is bred to a different sire.

With mean TA of young and TA old bulls both at $150, and Ro=.9, for example, a risk-neutral dairy producer would select the alternative with highest expected income regardless of risk (i.e., they would use only young bulls). A completely risk-averse dairy producer would select the alternative with lowest risk; he would use only old progeny tested sires and a different sire for each cow. A dairyman with a completely risk-prone behavior would select a single young bull.

James (1977) reported that opening a nucleus herd has little effect on rate of gain with selection intensity of 10%. But, with selection intensity in females between 50 and 80%, opening the nucleus herd increases the steady rate of gain by 10 to 15%, the effects being greater when mates are more intensely selected.

Hunt et al. (1972), in a simulation, reported an increase in genetic gain annually as the number of sires of sons for entry in AI decreased from eight to two for different population sizes, although this advantage was directed solely towards milk yield. A large percentage of the cows should be on test and bred to young bulls when population size is small. Similar estimates of annual genetic gain (1.52 BCA/year) occurred in a population of 15,000 cows, when 60% were tested and 40% of these bred to young bulls,and in a population of 115,000 cows, when 20% were tested and 20% of these bred to young bulls. Greater genetic gains per year were achieved by small progeny group sizes (20 daughters) in small populations, and by intermediate progeny group sizes (40 to 60 daughters) in large populations.

Least square means for milk yield in the January, 1991 USDA animal model evaluations for Holsteins were -262, -196, and -75 kg for unused AI, heavily sampled AI, and unused non-

AI bulls, and 87 and 84 kg for AI bulls and non-AI bulls returned to service. These results were present by Cassell et. al. (1992) in a study on genetic merit and usage patterns of bulls from different sampling programs.

Hinks (1970) worked on selection of dairy bulls for artificial insemination. He found that the optimal size of the test group was relatively insensitive to variation in population size, ranging from 65 daughters per sire in a population of 100,000 to 75 in a population of 800,000. The results in this study indicated that increases in the annual intake of young bulls, sufficient to permit an increase in the rate of selection from 1 in 4 to 1 in 6, are likely to prove highly profitable to the industry, despite an increase in testing costs.

Hinks (1970) also found that the collection and slaughter program induces a larger selection response for a given rate of selection. This can be attributed partly to an increase in testing accuracy associated with larger test groups and partly to a reduction in the length of generation interval.

Lindhe (1968) reported that with 75,000 doses of deep frozen semen from each bull, the maximum is 40% inseminations with young bulls, 50% for 30,000 and 15,000 doses, and greater than 70% if only 5,000 doses are deep frozen from each bull. All the five alternatives give the same technical results, but the freezing and storage costs increase with an increasing number of bulls. If the number of deep frozen doses in the above alternatives is increased (i.e. from 20,000 to 40,000), the marginal rate of return becomes 8%. If the number of bulls is increased (i.e., from 117 to 222) with the number of doses held constant then the marginal rate of return is 6%.

Dimitre and Grinberg (1983) reported 35 to 45% annual culling rate of AI bulls. They concluded that it was now possible to inseminate about 60% of females with semen of improver bulls.

Genetic gain and inbreeding

Hillers and Freeman (1964) measured effects of inbreeding, line breeding, and selection in a small, closed Guernsey herd which was a replicate of an experiment with a larger herd of Holstein cattle. Inbreeding was as high as 31%, with an average of 6.4% for all cows. The total genetic improvement per year expected from the selection of parents, expressed as a percent of the herd average was .33% for milk, .57% for milk fat yield, and .40% milk fat percentage.

Hillers and Freeman (1964) reported that the intra-sire regressions of production on percent of inbreeding obtained from the analysis of covariance and the weighted average regressions, respectively, were -36 and -51 lb of milk per 1% inbreeding, -1.7 and -2.3 lb of milk fat per 1% inbreeding, and +.001 and +.002% test per 1% inbreeding. The intra-sire regressions of weight on percent inbreeding were -0.3 lb at birth, -0.7 lb at six months, -1.5 lb at one year, -1.9 lb at two years, -1.4 lb at three years, -4.5 lb at 4 years, and -3.2 lb at five years. The intra-sire regressions of production on coefficient of relationship to a superior foundation cow were -.6 lb milk fat, -21 lb of milk, and +.006% milk fat test.

Goddard (1990) worked on optimization of the number of bull sires in dairy cattle breeding. He reported that the effect of level of inbreeding depression on the number of bull sires to maximize the net response is quite large. With a 1% depression of economic merit per 1% inbreeding, the number of bull sires needed is about two to three times greater than with an inbreeding depression of .25%/1% inbreeding.

The level of inbreeding for the optimum schemes, those yielding the maximum net response, are quite low. With 10 bull sires per generation (5 yr) used in the dispersed breeding nucleus, the estimated inbreeding per year is 1/(5(8)10)=.0025 or.25%/yr,and .125%/yr with 20 bull sires per generation. These figures can be compared with current effective rates of inbreeding in North American Holsteins of about .19%/yr.

In a study on minimization of inbreeding in small scale selection programs, Toro et al. (1988) reported that the average inbreeding attained with a minimum of co-ancestry mating and by using a weighted selection system (i.e., a large number of pairs may be selected, with each pair making unequal contributions to the offspring, based on performance, while maintaining the same selection differential), as proposed by Toro and Neito (1984), was less than with any other system. The decreased inbreeding coefficient with respect to random mating system was as much as 30%.

In a study on Canadian Jerseys (Fillippo et al. 1992), the regression coefficients of milk yield, fat yield, and fat percentage on inbreeding were -9.84 kg, -0.55 kg, and -0.0011% per 1% increase of inbreeding. Inbreeding depression was not enough to cause large reductions of milk and fat yield with average inbreeding of 3.3% in inbred cows. However, when the inbreeding coefficient was greater than 12.5%, the inbreeding depression was significantly higher than expected.

Hudson and Van Vleck (1984) reported average inbreeding coefficients of 6, 4, 1, 2, and 2% for Ayrshire, Guernsey, Holstein-Friesian, Jersey and Brown Swiss dairy cattle in the northeastern United States. The percentage of inbred cows in the five breeds, respectively, was 26, 11, 31, 23, and 23%. Inbreeding depression increased as the inbreeding coefficient increased up to 15%. They concluded, however, that there is no concern over current inbreeding in the United States, but active inbreeding is not recommended.

Hudson and Van Vleck (1984) reported regression of 305 day mature equivalent milk and fat yields (kg) on inbreeding coefficient (%) for Ayrshires, -27.1 and -1.2, Guernseys,

-19.3, and -0.97, Holstein-Friesians -21.1 and -0.78, Jerseys -14.8, and -0.80, and Brown Swiss -39.5 and -1.36.

Regression

The development of methods to predict a young bull's progeny test has been implemented by using different sources of relative information. Some relatives have more information than others and this affects the accuracy of prediction, however, there may be other uncontrollable circumstances making the information from some relatives less effective than theoretically expected. Therefore, regression analyses have been used to identify strengths and weaknesses of information from different classes of relatives. Vinson and Freeman (1972) found that the regression coefficient estimates of young bulls progeny tests on their sires, dams and mid-parents (sire + dam) were 0.4, 0.43, and 0.43 for milk yield and 0.41, 0.39, and 0.34 for fat yield.

Major improvements in genetic prediction technology have been developed over the last two decades. Estimates of genetic trends for traits under selection are considered to be good measures of the genetic change realized by the application of new improved technology.

Lee et al. (1985) estimated genetic trend in the registered Holstein cattle population. They found the rates change for genetic merit of sires were larger than corresponding changes in dams. Steady increases in predicted difference milk (PDM) of sires of male and female progeny occurred between 1968 and 1979 and were 539 and 450 kg, respectively. As PDM of sires increased, a decline in sire PD fat percent (PDF%) occurred. From 1960 to 1979, overall changes in average PDF% of sires were only -0.04 for male offspring and -.06 for female progeny. In contrast to sire PDM, average cow index milk (CIM) of dams was larger for male progeny in all years.

Van Tassel and Van Vleck (1991) estimated genetic trend for milk yield in Holsteins in the four paths of selection. The estimates of genetic trends for the sires of bulls path of selection from 1955 to 1973 were 60.8 and 53.1 kg per year, weighted by number of sons and unweighted, respectively. The overall annual genetic change for dams of bulls born from 1955 to 1975 was 25.8 kg per year, whereas the estimate of recent genetic gain (dams born from 1968 to 1974) for that path was 59.0 kg per year. The estimates of genetic trend for sires of cows did not show the dramatic improvement seen in the other selection paths. The estimates of trend for all years (sires born from 1955 to 1978) for SC were 27.4 and 39.5 kg per year for weighted and unweighted means. The estimates of recent genetic trend for SC (sires born from 1968 to 1978) were -4.2 and 48.2 kg per year for weighted and unweighted means. For dams of cows, the overall estimate of annual genetic change for dams born from 1955 to 1979 was 16.0 kg per year. Whereas the estimate of the recent trend for dams born from 1968 to 1978 was 28.5 kg per year.

Burnside et al. (1992) studied estimates of breeding values for milk, fat, and protein yields of Italian Friesian cows born from 1972 to 1988. The genetic trend from 1985 to 1988 was characterized by rapid genetic improvement of the cow population for milk, fat, and protein yields. The annual genetic change averaged 6.0 kg of protein, 6.33 kg of fat, and 173 kg of milk per year. Annual genetic change prior to 1985 was substantially lower and averaged 1.7, 2.0, and 57.2 kg for protein, fat, and milk yield, respectively.

Murphy et al. (1982) calculated multiple regression coefficients on genetic evaluations of about 170 bulls by using sire, dam, and maternal grandsire (MGS) evaluations. They found that the partial regression coefficients were 0.45, 0.12, 0.07 for the sire, the dam, and MGS, respectively, using all lactations. When only the cow's first lactation record and her herd-mates were used, the partial regression coefficient was 0.33. When MGS's proof and only dam's first record were used, the partial regression coefficient for MGS was 0.02. They concluded that preferential treatment of bull dams could result a bias in prediction of a son's pedigree index when all lactations for dam are used to estimate her transmitting ability.

Jeon (1986) found that the regression coefficient for dam's estimated transmitting ability based on all lactations were very small and close to zero. He concluded that the evaluation for dams based on later lactations were not as predictive of bulls predicted differences as expected.

The development of young sires to enhance the genetic merit of dairy cattle in the United States is a national cooperatives effort. Young sires sampling programs are managed in the private sector by cooperatives, private companies and syndicates of a few breeders. Breed associations help to identify the top candidates for young sires sampling at the time of registration with performance pedigrees circulated to interested individuals. Semen from all bulls is available to all dairy producers on a commercial basis. The owners of dairy cattle through the country provide the data for national sire evaluations. The National Cooperatives Dairy Herd Improvement Program sets standards for record keeping and coordinates the processing of records. Genetic evaluations are conducted biannually by the United States Department of Agriculture (USDA) Animal Improvement Programs Laboratory (AIPL) and this information is made available to all breeders of dairy cattle.

The USDA, breed associations and private companies have developed programs and policies emphasizing the need for continued genetic improvement. Sire summary rankings provided by the USDA-AIPL have made it possible to recognize superior proven bulls for over 25 years. The objective of this thesis is to focus on the Jersey breed of dairy cattle to characterize the genetic changes that have occurred and to determine areas for potential improvement.

To progress and remain competitive the American Jersey Cattle Club (AJCC) feels it is essential that breeders continue sampling young sires. In 1980, the AJCC initiated a Young Sire Program (YSP) to insure early and accurate multi-herd proofs. Some young Jersey bulls are also progeny tested in other programs, however, the AJCC-YSP is primarily responsible for progeny testing Jersey bulls. Over 300 Jersey breeders have been or continue to be involved in this program. Their contribution to Jersey sire sampling is noteworthy as over 70 more Jersey bulls have been sampled since 1985 (C. Wolfe. 1992. Personal Communication). Qualifications and standards for the YSP have change over time. Currently, top candidates for young sire sampling are identified at the time of registration with performance pedigrees circulated to interested individuals. To qualify for the YSP young bulls must: 1) have a parent average of +268 PTI or 45 pounds protein, and 2) have less than 12.5% inheritance from a designated abnormality carrier (C. Wolfe. 1992. Personal Communication), where

$$PTI = [4(\text{PTA protein}/SD_{\text{PTA protein}}) + 1(\text{PTA fat}/SD_{\text{PTA fat}}) + 1(\text{FTI}/SD_{\text{FTI}})](100/6),$$

PTA = predicted transmitting ability

SD = standard deviation, and

FTI = functional trait index.

The AJCC also endorses the use of selected young sires on 25 to 40% of the herd, with an understanding that this should include a significant number of heifer matings. The intent here is to reduce generation interval by using more young bulls in heifer AI programs. The specific objectives of this research are to: 1) estimate generation intervals and realized genetic selection differentials for the four paths of genetic improvement (i.e., sires of bulls, dams of bulls, sires of cows and dams of cows) for the Jersey breed, and 2) estimate the genetic response in milk yield, fat yield, fat percentage, protein yield and protein percentage.

MATERIALS AND METHODS

Predicted transmitting abilities (PTA) for all registered cows (n = 508,828) and sires (n = 7942) in the Jersey breed were obtained from the USDA-AIPL. PTA's were calculated by using an animal model (Wiggins and VanRaden, 1989; VanRaden and Wiggins, 1991). Cows were born from 1960 to 1989 with lactations recorded prior to June, 1992. The data set included PTA's for milk yield, fat yield, fat percentage, protein yield, protein percentage, year of birth, sire and dam identification. All PTA's were calculated relative to the breed average of first lactation cows born in 1985 and are some times called PTA-Base 1990 or simply PTA90.

Selection differentials and generation intervals

Average PTA's were calculated by year of birth for each selection path (Figure 1). Averages were calculated in two ways for each path of selection: 1) weighted by the number of progeny; and 2) unweighted. The weighted average was interpreted as a representative measure of the type of sire or dam used as parents to produce bulls or cows. Whereas, the unweighted average estimated the genetic value of the sires or dams available for breeding.

Selection differentials were calculated as the average difference for each of the selected groups from the average PTA of all cows born in the same year. Cows born in a given year were used as the base for comparison in calculating all

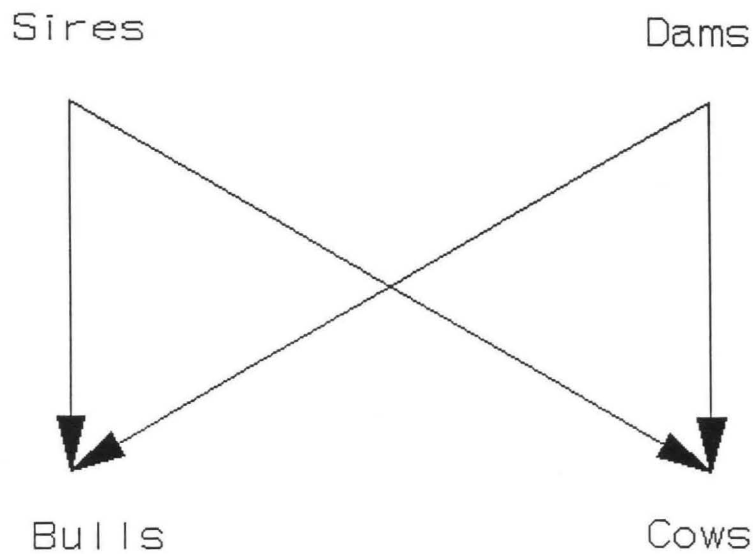


Figure 1. Paths of selection

selection differentials because they were an unselected group of animals. Estimated selection differentials and generation intervals for milk yield were compared with potential selection differential and generation interval suggested by Van Tassell and Van Vleck (1991) for Holsteins (Table 1).

The average generation intervals for young AI bulls and replacement females were calculated by year of birth from the average age of sires or dams when their offspring were born.

Genetic Trend

Average genetic trend for each path of selection was calculated as the regression of average PTA values of milk yield, fat yield, fat percent, protein yield, and protein percent, on time. Time was considered as year of birth of the

Table 1. Assumptions used to calculate potential selection differentials and annual genetic change.[1]

Selection paths	Accuracy	Selection intensity	Genetic SD	Generation Interval
		%	kg	
Sire of bull	0.75	5	570	7
Dam of bull	0.65	5	570	5
Sire of cow	0.85	20	570	8
Dam of cow	0.65	90	570	5

[1] Van Tassell and Van Vleck (1991).

sire or dam of the bull or cow. Yearly averages of estimated PTA values were used so that each year had equal weight in the estimated selection differential. Weighted and unweighted means were used for all four paths to account for different sire usage in each birth year. In addition, regression coefficients were computed for two time periods: all years, and last five years i.e., 1960 to 1987. Previous studies on Holsteins by Van Vleck (1991), Lee et al. (1985), and Powell et al. (1977) indicated 1968 as the approximate time when changes in genetic trend occurred.

Annual genetic change

Expected genetic improvement per year (Δ g) was calculated using the formula suggested by Rendel and Robertson (1950):

$$\Delta g = \frac{\Delta G_{SB} + \Delta G_{DB} + \Delta G_{SC} + \Delta G_{DC}}{L_{SB} + L_{DB} + L_{SC} + L_{DC}}$$

where ΔG is the estimated genetic superiority of the selected group over their contemporaries in the base group born in the same year and L is the average age of the selected animals when their offspring were born.

Expected yearly genetic gain for milk yield, fat yield, fat percent, protein yield, and protein percent also were estimated using the regression estimates as suggested by (Van Tassell and Van Vleck, 1991)

$$\Delta g = 1/4\ (2b_{PTASB} \cdot T + 2b_{PTADB} \cdot T + 2b_{PTASC} \cdot T + 2b_{PTADC} \cdot T\ ).$$

RESULTS AND DISCUSSION

Generation intervals

The generation interval by year of birth was calculated for young AI bulls and replacement females from 1965 to 1990. There were a total of 5,387 young AI bulls, and 393,678 replacement females for the period reported above. The generation intervals for the four paths of selection (i.e. sires of young bulls, dams of bulls, sires of cows, and dams of cows) are given in Table 2. There was a nonlinear trend in the generation intervals for parents of young bulls (Figure 2). The generation interval for sires of bulls increased from 8.0 yr in 1965 to 11.5 yr in 1978 and then gradually declined to 7.2 yr in 1990. The generation interval for dams of bulls increased from 3.9 yr in 1965 to 6.2 yr in 1970, remained relatively constants from 1970 to 1985, and gradually declined from 1985 to 1990. Average generation intervals for replacement females are given in Figure 3. The generation interval for sires of cows was relatively constant over the 25 yr period from 1965 to 1990, as was the generation interval for dams of cows. Table 3 summarizes the generation intervals over all years, from 1975 to 1984, and from 1985 to 1990. Sires of bulls tended to have higher average generation intervals than what was considered to be optimum for genetic improvement by Van Tassell and Van Vleck (1991). From 1975 to 1984, the average generation interval was higher than in

Table 2. Total size of young AI bull and female replacement population and average generation intervals (years).

Birth year	Young AI bulls n	L_{SB}[1]	L_{DB}[2]	Replacement females n	L_{SC}[3]	L_{DC}[4]
1965	74	8.0	3.9	2847	7.1	3.5
1966	126	8.0	4.4	3548	7.2	3.8
1967	128	8.4	4.9	4093	7.3	4.1
1968	129	7.9	5.4	4715	7.4	4.4
1969	151	8.4	5.6	5449	7.4	4.6
1970	166	9.1	6.2	6016	7.5	4.7
1971	202	9.5	6.2	7003	7.5	4.8
1972	238	10.3	6.5	7618	7.9	4.9
1973	256	9.9	6.6	8396	7.7	4.9
1974	222	10.4	6.5	9248	7.6	4.8
1975	230	10.5	6.8	10069	7.4	4.8
1976	231	10.3	6.6	11598	7.5	4.8
1977	242	10.9	6.0	13476	7.7	4.8
1978	257	11.5	6.3	15824	7.9	4.8
1979	231	11.3	6.7	18244	7.8	4.8
1980	277	10.7	6.3	21552	7.9	4.7
1981	293	9.7	6.4	24347	7.8	4.6
1982	268	10.4	6.4	25435	7.8	4.6
1983	268	9.2	6.1	26382	7.7	4.5
1984	295	9.1	6.3	27168	7.5	4.5
1985	263	9.3	6.1	26681	7.9	4.4
1986	252	7.9	5.3	28050	7.7	4.4
1987	189	8.0	5.3	28317	7.6	4.4
1988	131	7.9	4.6	28277	7.8	4.4
1989	133	7.8	4.4	25956	7.5	4.4
1990	135	7.2	3.8	3369	7.3	4.2

[1]L^{SB} = generation interval for sires of bulls.
[2]L_{DB} = generation interval for dams of bulls.
[3]L_{SC} = generation interval for sires of cows.
[4]L_{DC} = generation interval for dams of cows.

Figure 2. Average generation intervals by year of birth for sires of bulls ■, and dams of bulls +.

Figure 3. Average generation intervals by year of birth for sires cows ■, and dams of cows +.

earlier or more recent years because of the higher use of old proven bulls. From 1985 to 1990, however, the average generation interval for sires and dams of bulls was more nearly optimum due to the increased use of young AI bulls. The average generation interval for sires of cows and dams of cows was relatively constant over all years, and is almost the same as potential intervals reported by Van Tassel and Van Vleck (1991). Dairy producers need to reduce the generation interval for the sires of bulls path to a level suggested by the potential interval, so they can achieve more nearly optimum genetic gain. Generation intervals for this path can be efficiently reduced by using a higher percentage of young AI bulls.

Table 3. Estimated and potential generation intervals.

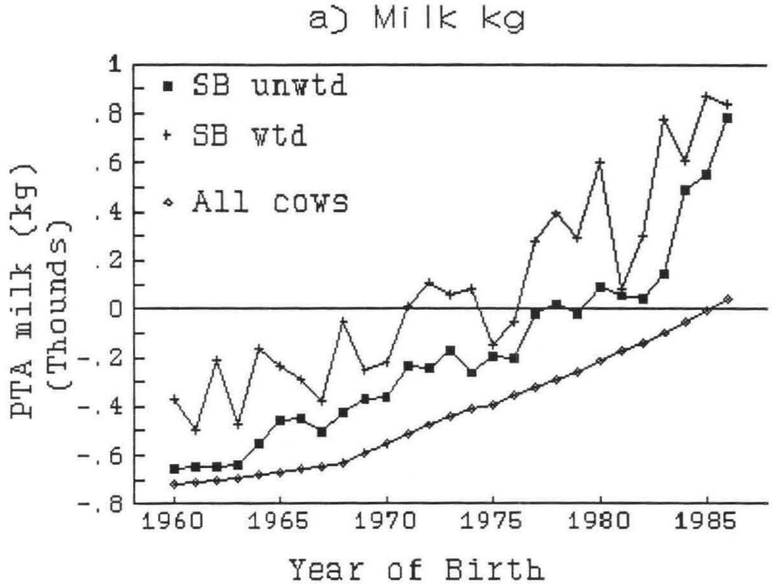
Selection path	Overall average	1975 to 1984	1985 to 1990	Potential interval[1]
Sire of bull	9.3	10.4	8.0	7
Dam of bull	5.8	6.4	4.9	5
Sire of cow	7.6	7.7	7.6	8
Dam of cow	4.5	4.7	4.4	5

[1] Van Tassel and Van Vleck (1991)

Genetic selection differentials

Estimates of annual genetic selection differentials for the four paths of selection are given in Tables 7 to 14 in the Appendix. The data are presented graphically in the body of the text by plotting the average PTA of parents (weighted by the number of progeny and unweighted) versus their respective years of birth. The average PTA of the unselected base group (i.e., all cows born in the same years) is also included in each figure to provide a basis for comparison of trends.

Sires of bulls. The yearly average PTA for SB and selection differentials (i.e., the differences between the weighted or unweighted average PTA of parents and the average of all cows born in the same year) are given in Figure 4 (a to d). Selection differentials for milk and fat yield tended to increase after 1964. The weighted averages tended to be higher than the unweighted averages (i.e., better bulls were used more frequently), but they were also more variable from year to year. Van Tassell and Van Vleck (1991) also reported an increasing trend in genetic selection differentials for milk yield in Holstein cattle. The weighted and unweighted PTA values for fat percentage were quite variable (Figure 4c). It seems from Figure 1c that there was selection for lower fat percentage before 1980, but selection for increased fat percentage after 1980. There was more intensive selection for protein yield for SB born after 1977 (Figure 4 d). The selection differentials for milk yield in Jersey cattle were higher than values reported by Miller (1961) and Lytton (1969). More intense selection for fat yield is also indicated here than reported by Lytton (1969), however, selection



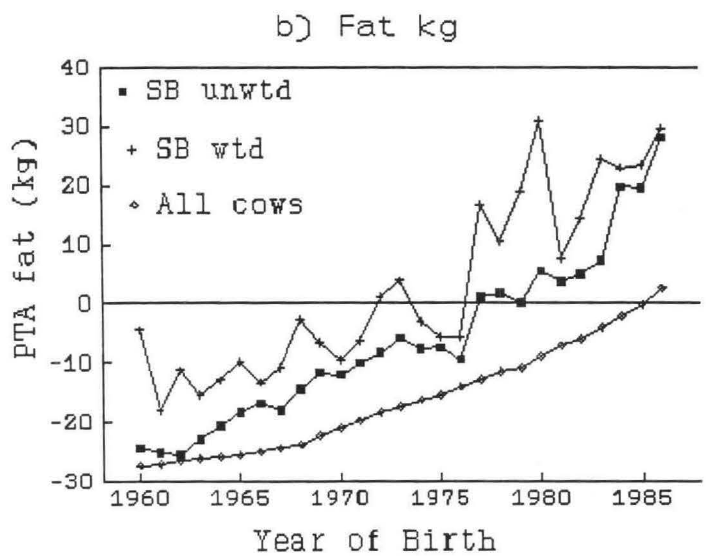


Figure 4. Average predicted transmitting ability (PTA) of sires of bulls weighted by number of sons (SB wtd) and sires of bulls unweighted (SB unwtd) by year of birth of sires compared with average PTA of all cows born in the same year.

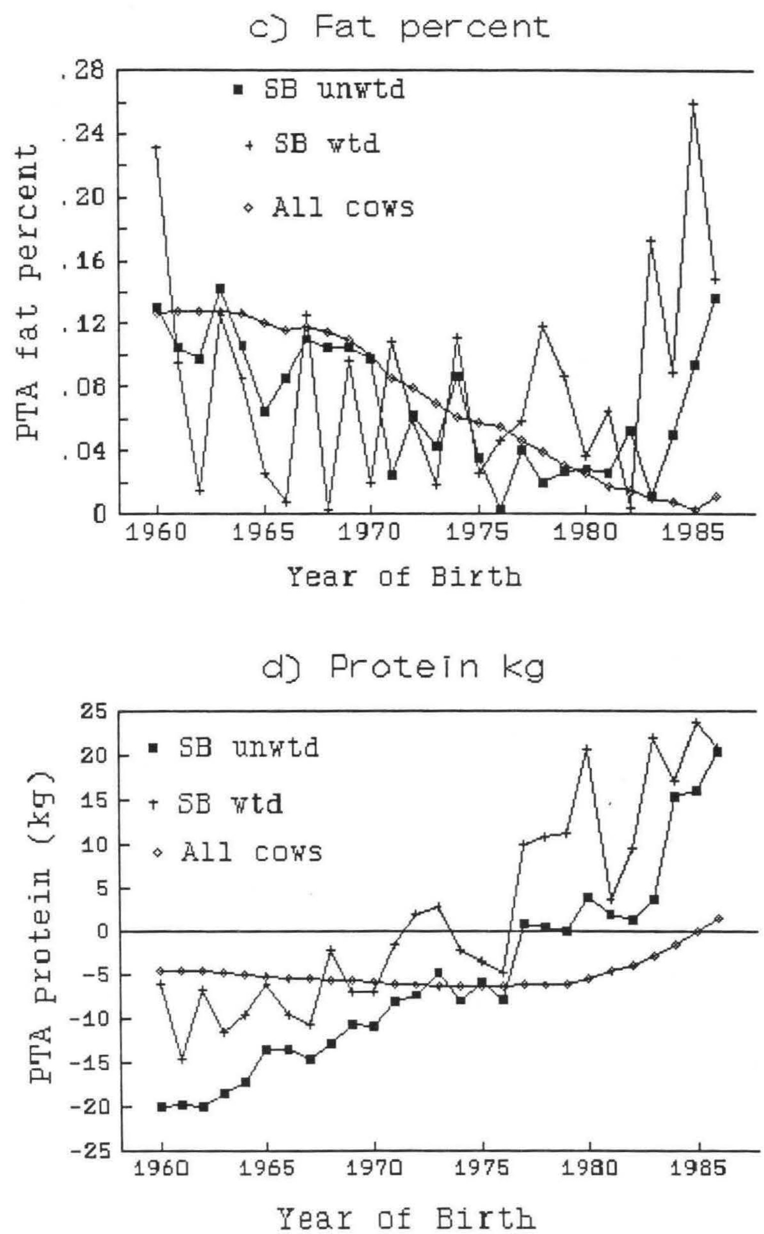


Figure 4. (cont.) Average predicted transmitting ability (PTA) of sires of bulls weighted by number of sons (SB wtd) and sires of bulls unweighted (SB unwtd) by year of birth of sires compared with average PTA of all cows born in the same year.

differentials for fat percentage were lower than values reported by Miller (1961) and Lytton (1969). These results show that there was selection for milk and fat yield, butselection against fat percentage.

The selection differentials, weighted by the number of sons and unweighted, are summarized in Table 4. In the last five years selection differentials for milk yield, fat yield, protein yield, and fat percentage were higher than the overall average. Unweighted selection differentials for protein percentage were higher from 1960 to 1986 than in the last 5 years. The average selection differential for protein percentage in the last five years was lower than the overall average.

Dams of bulls. Average PTA for DB, weighted by number of sons and unweighted, were higher than the average of all cows born in the same year for milk and fat yield (Figure 5 a and b). The estimated yearly average selection differentials for milk yield, fat yield, and protein yield were higher in the last five years than the overall average (Table 4). Selection differentials for fat percentages were negative, and lower in the last five years than the overall average. Unweighted and weighted selection differentials for protein percentages were positive and higher from 1960 to 1987 than in 1983 to 1987. Negative selection differentials for fat and protein percentage show that there was selection against these

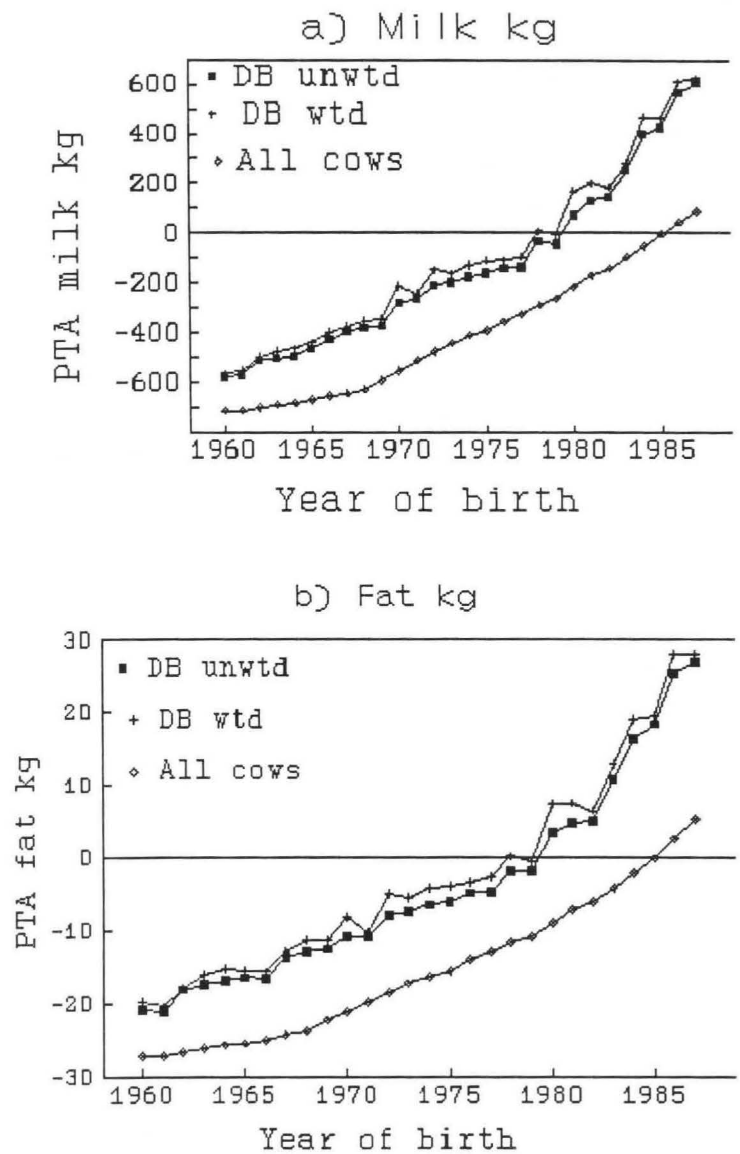
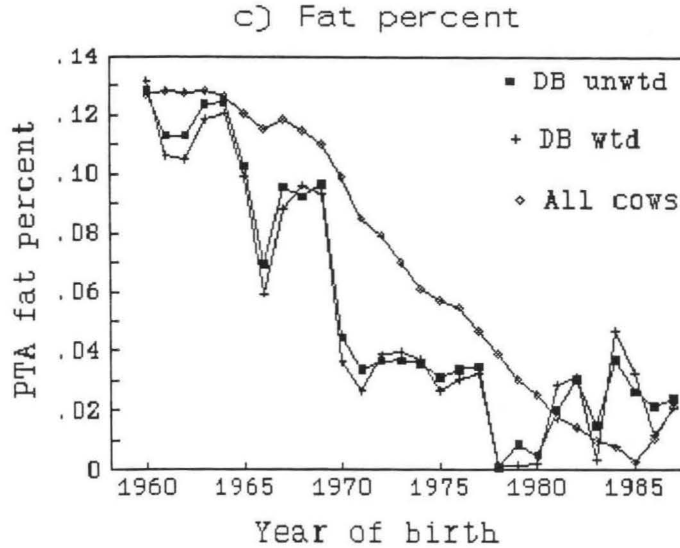


Figure 5. Average predicted transmitting ability (PTA) of dams of bulls weighted by number of sons (DB wtd) and dams of bulls unweighted (DB unwtd) by year of birth of dams compared with average PTA of all cows born in the same year.



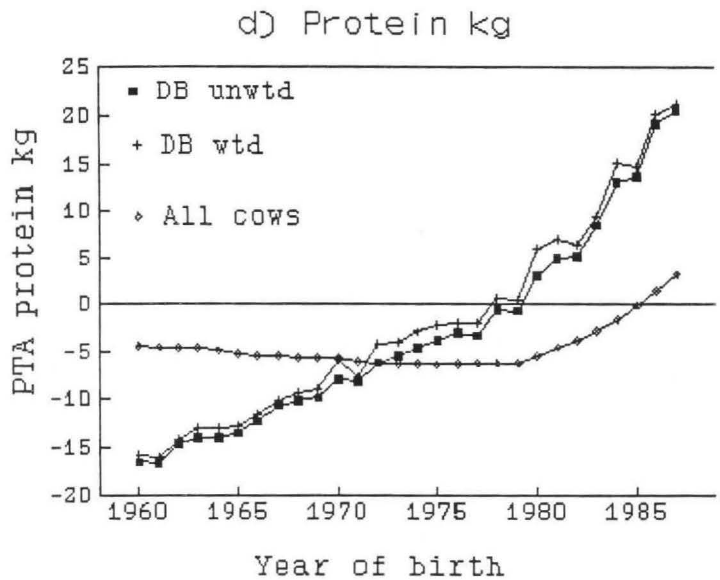
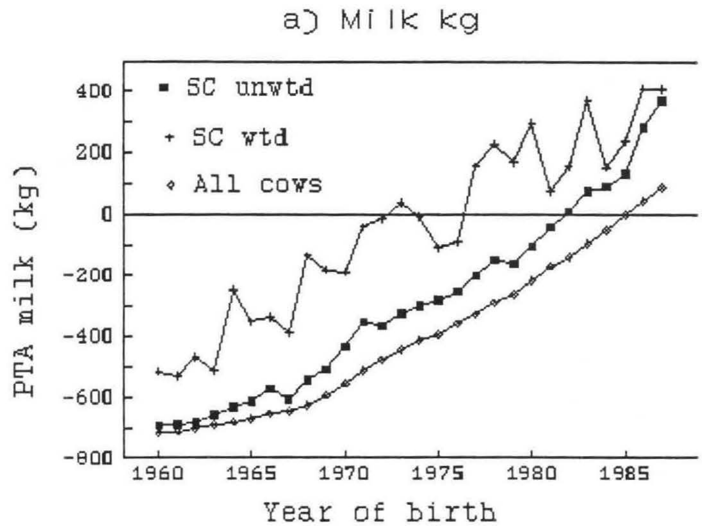


Figure 5. (cont.) Average predicted transmitting ability (PTA) of dams of bulls weighted by number of sons (DB wtd) and dams of bulls unweighted (DB unwtd) by year of birth of dams compared with average PTA of all cows born in the same year.

components of merit from 1983 to 1987.

Sires of cows. The yearly average PTA for SC and selection differentials are given in Figure 6 (a to d). There was moreintense selection for milk yield for SC after 1969 than in earlier years (Figure 6 a). The weighted PTA of SC was higher than the unweighted PTA average, but they were also more variable from year to year. The estimated weighted selection differentials for SC were higher for protein yield, fat percentage and protein percentage in last five years compared to the overall average (Table 4). The weighted selection differentials for milk yield and fat yield were lower in the last five years than the overall average.

Dams of cows. The yearly average PTA for DC and selection differentials are given in Figure 7 (a to d). Selection of DC was less intense than in the other paths, as expected due to the low reproductive rate of dairy cows. The weighted selection differentials for DC were higher than the unweighted selection differentials for milk yield, fat yield and protein yield, but lower for fat percentage and protein percentage (Table 4). Selection differentials for fat and protein percentage were lower in the most recent five years than the overall average, but there was relatively little change over this period.



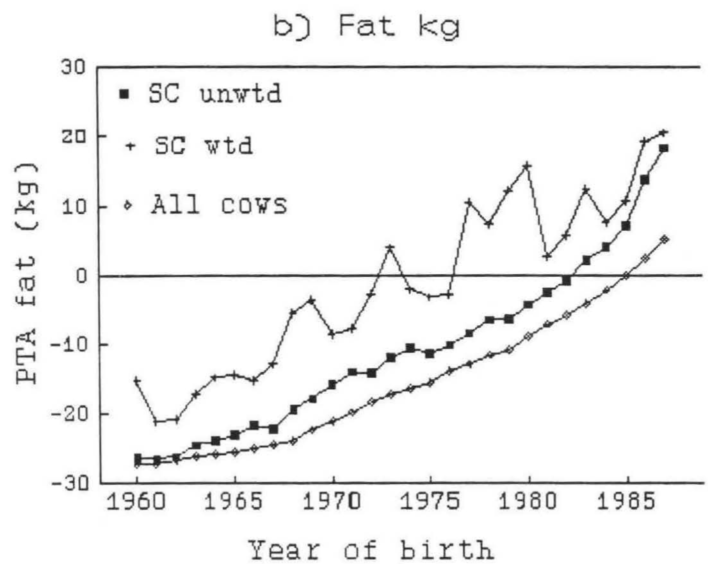
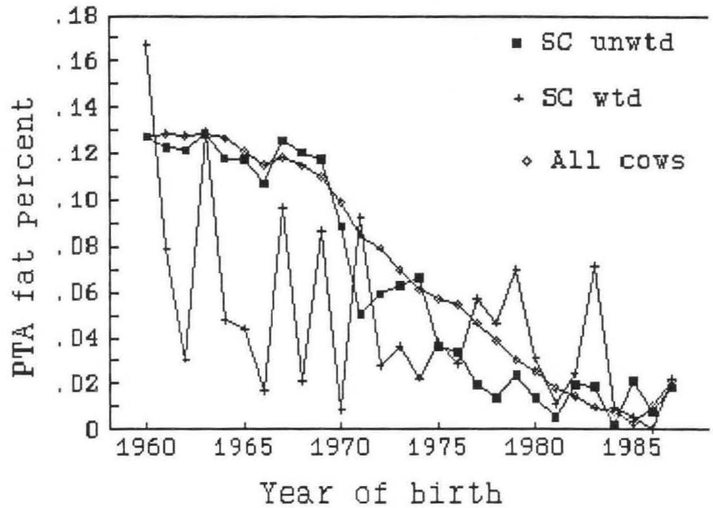


Figure 6. Average predicted transmitting ability (PTA) for sires of cows weighted by number of daughters (SC wtd) and sires of cows unweighted (SC unwtd) by year of birth of sires compared with average PTA of all cows born in the same year.

c) Fat percent



d) Protein kg

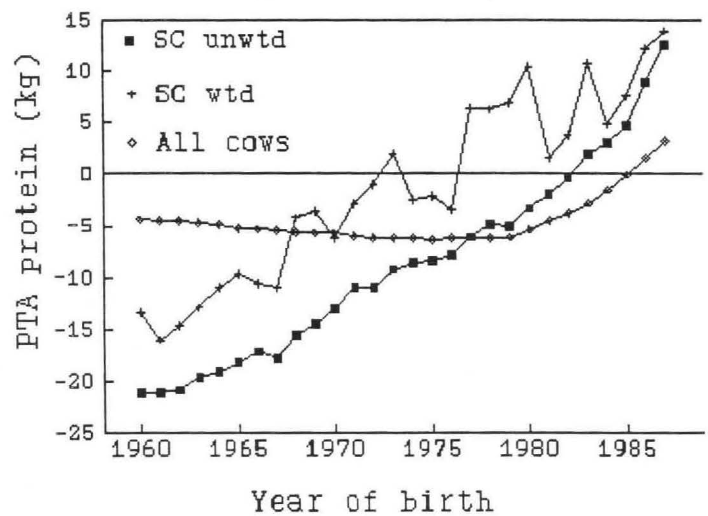
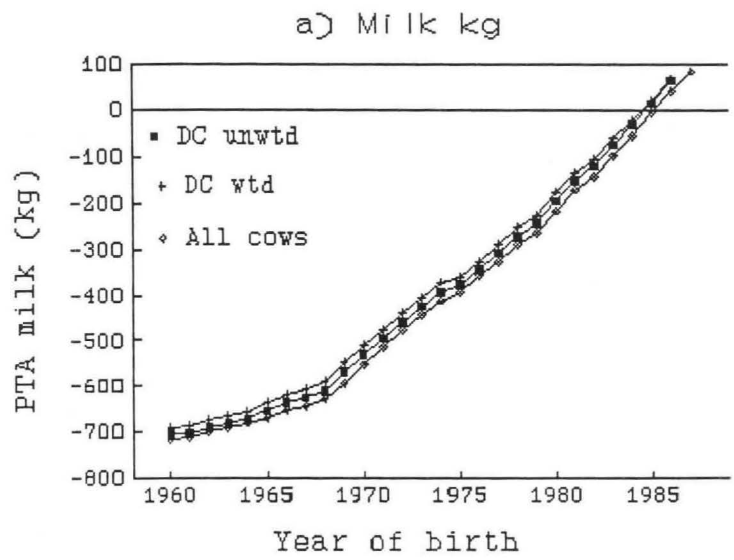


Figure 6. (cont.) Average predicted transmitting ability (PTA) for sires of cows weighted by number of daughters (SC wtd) and sires of cows unweighted (SC unwtd) by year of birth of sires compared with average PTA of all cows born in the same year.



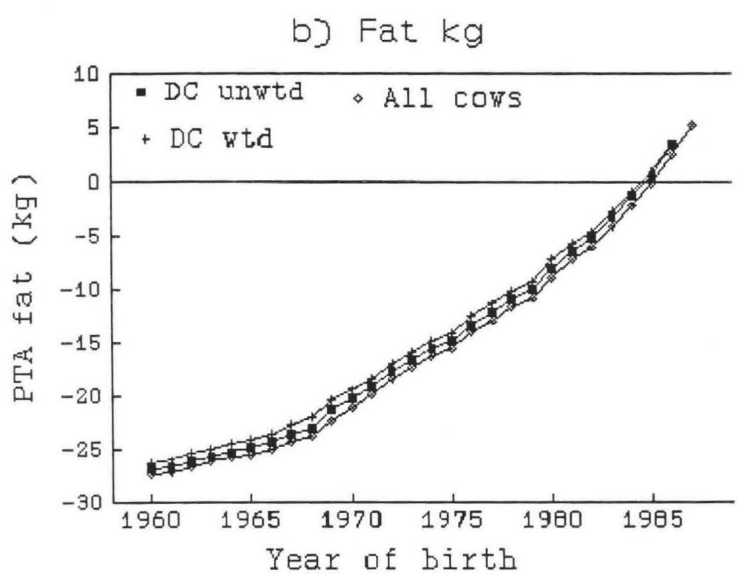
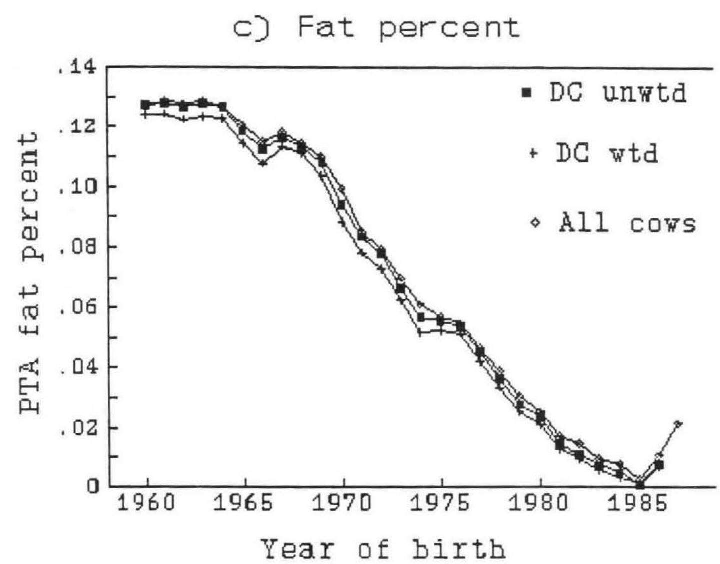


Figure 7. Average predicted transmitting ability (PTA) for dams of cows weighted by number of daughters (DC wtd) and dams of cows unweighted (DC unwtd) by year of birth of dams compared with average PTA of all cows born in the same year.



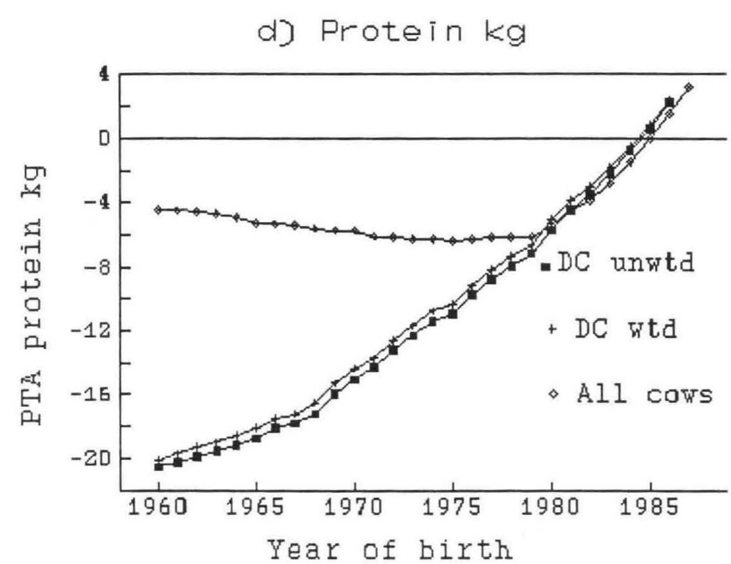


Figure 7. (cont) Average predicted transmitting ability (PTA) for dams of cows weighted by number of daughters (DC wtd) and dams of cows unweighted (DC unwtd) by year of birth of dams compared with average PTA of all cows born in the same year.

Table 4. Estimated selection differentials.

Selection path	Overall average					Last 5-yr average				
	Milk (kg)	Fat (kg)	Protein (kg)	Fat (%)	Protein (%)	Milk (kg)	Fat (kg)	Protein (kg)	Fat (%)	Protein (%)
Sires of bulls	(1960 to 1986)					(1982-1986)				
Weighted	492.94	18.86	6.69	0.0114	0.0282	730.48	24.88	19.93	0.1255	0.0853
Unweighted	239.86	10.00	-0.73	-0.0014	0.0247	454.98	17.89	12.74	0.0599	0.0443
Dams of bulls	(1960 to 1987)					(1983-1987)				
Weighted	306.66	12.08	2.54	-0.0172	0.0195	494.71	21.22	16.08	0.0128	0.0257
Unweighted	269.11	11.22	1.36	-0.0148	0.0227	455.57	19.32	14.94	0.0144	0.0234
Sires of cows	(1960 to 1987)					(1983-1987)				
Weighted	351.17	14.00	3.09	-0.0224	0.0114	321.06	13.81	9.81	0.0113	0.0222
Unweighted	108.69	4.59	-4.27	-0.0065	0.0249	194.24	8.85	6.14	0.0033	0.0081
Dams of cows	(1960 to 1987)					(1983-1987)				
Weighted	34.23	1.43	-5.98	-0.0052	0.0275	29.27	1.16	0.92	-0.0034	-0.0010
Unweighted	18.05	0.74	-6.51	-0.0021	0.0309	22.43	0.89	0.71	-0.0027	-0.0003

Table 5. Estimated annual genetic change for milk, fat and protein yield for each path of selection.

Selection paths	Yr[1]	Milk kg Wtd	Milk kg Unwtd	Fat kg Wtd	Fat kg Unwtd	Protein kg Wtd	Protein kg Unwtd
Sires of bulls	a	28.62± 38.84	64.44±13.96	-0.32±1.34	2.62±0.44	-0.06±0.98	2.62±0.44
	b	110.10± 15.10	107.08±11.20	4.18±0.60	3.98±0.38	3.20±0.44	3.98±0.38
	c	232.04±105.08	378.78±43.80	6.00±2.12	11.74±1.96	4.86±3.00	11.74±1.96
	d	91.70± 8.58	90.06± 6.12	3.38±0.34	3.56±0.20	2.60±0.26	3.46±0.20
Dams of bulls	a	53.90± 3.18	51.02± 4.04	1.86±0.30	1.84±0.28	1.60±0.18	1.58±0.18
	b	99.54± 6.32	98.98± 6.36	4.02±0.32	3.98±0.32	3.08±0.20	3.06±0.22
	c	166.16± 34.04	175.98±21.76	7.86±1.36	8.26±0.88	5.74±1.04	6.06±0.78
	d	83.54± 4.02	81.32± 4.18	3.24±0.20	3.14±0.20	1.54±0.14	2.48±0.14
Sires of cows	a	59.82± 24.52	33.78± 5.34	1.58±0.76	1.50±0.18	1.42±0.44	1.22±0.14
	b	57.34± 7.18	84.00± 3.86	2.60±0.36	3.34±0.24	1.80±0.24	2.54±0.14
	c	66.64± 7.60	157.94±28.94	5.58±2.52	8.36±0.98	2.76±2.18	5.44±0.82
	d	67.38± 4.30	74.40± 2.66	2.82±0.20	2.90±0.14	2.04±0.14	2.26±0.08
Dams of cows	a	25.42± 1.52	123.46± 1.72	1.00±0.04	0.90±0.06	0.84±0.02	0.80±0.04
	b	71.46± 1.08	73.30± 1.28	2.76±0.08	2.84±0.10	2.06±0.04	2.12±0.06
	c	84.92± 0.90	91.80± 1.18	4.38±0.26	4.64±0.26	2.90±0.10	3.12±0.12
	d	61.68± 1.80	62.30± 2.02	2.34±0.08	2.36±0.10	1.78±0.06	1.80±0.06

[1]a = 1960 to 1967:
b = 1968 to 1986 for SB; 1968 to 1987 for DB, SC, and DC.
c = Last five yrs: SB 1982 to 1986, DB 1983 to 1987, SC 1983 to 1987, and DC 1983 to 1987.
d = Over all: SB 1960 to 1986, DB 1960 to 1987, SC 1960 to 1987, and DC 1960 to 1987.

Table 6. Estimated annual genetic change for fat and protein percentages for each path of selection.

Selection paths	Yr[1]	Fat percentage Wtd	Fat percentage Unwtd	Protein percentage Wtd	Protein percentage Unwtd
Sires of bulls	a	-0.0280±0.0220	-0.0090±0.0072	-0.0168±0.0106	-0.0052±0.0038
	b	0.0118±0.0048	-0.0018±0.0032	-0.0082±0.0030	0.0004±0.0026
	c	0.0756±0.0548	0.0502±0.0198	0.0572±0.0120	0.0570±0.0104
	d	0.0026±0.0034	-0.0054±0.0018	0.0008±0.0020	-0.0036±0.0014
Dams of bulls	a	-0.0132±0.0052	-0.0112±0.0010	-0.0066±0.0016	-0.0052±0.0014
	b	-0.0114±0.0046	-0.0114±0.0046	-0.0030±0.0012	-0.0042±0.0012
	c	-0.0088±0.0020	-0.0086±0.0020	0.0032±0.0060	0.0032±0.0046
	d	-0.0084±0.0010	-0.0088±0.0010	-0.0052±0.0008	-0.0058±0.0006
Sires of cows	a	-0.0200±0.0152	-0.0026±0.0020	-0.0128±0.0084	-0.0016±0.0024
	b	-0.0034±0.0020	-0.0052±0.0007	0.0002±0.0010	-0.0148±0.0020
	c	-0.0218±0.0170	-0.0010±0.0030	-0.0038±0.0116	0.0072±0.0056
	d	-0.0052±0.0016	-0.0110±0.0008	-0.0038±0.0010	-0.0074±0.0006
Dams of cows	a	-0.0044±0.0012	-0.0042±0.0010	-0.0016±0.0004	-0.0014±0.0004
	b	-0.0112±0.0008	-0.0116±0.0008	-0.0094±0.0002	-0.0088±0.0002
	c	0.0058±0.0034	0.0050±0.0040	-0.0046±0.0014	-0.0038±0.0012
	d	-0.0108±0.0004	-0.0112±0.0004	-0.0078±0.0004	-0.0074±0.0002

[1]a = 1960 to 1967
b = 1968 to 1986 for SB; 1968 to 1987 for DB, SC, and DC.
c = Last five yrs. SB 1982 to 1986, DB 1983 to 1987, SC 1983 to 1987, DC 1983 to 1987.
d = Overall: SB 1960 to 1986, DB 1960 to 1987, SC 1960 to 1987,DC 1960 to 1987.

Genetic gain per year

Genetic trends in these data were estimated from twice the linear regression of weighted and unweighted PTA means on birth year for the four paths of selection. The annual genetic response for milk, fat, and protein yields are presented in Table 5.

The genetic response estimated by twice the weighted PTA milk, fat, and protein yield on birth year for SB was higher in the recent five years (i.e. 1982 to 1986) at 232.04 kg, 6.00 kg, and 4.86 kg respectively, than the overall genetic response, i.e., 91.70 kg, 3.38 kg, and 2.60 kg respectively, (Table 5). Van Tassel and Van Vleck (1991) reported genetic gains of 60.8 kg (weighted) and 53.1 (unweighted) for SB in Holsteins from 1955 to 1973. Estimates of annual genetic response for fat and protein percentage were higher in the last five years than over all years. The results presented above suggest that there was more extensive use of high ranking bulls on the basis of PTA milk yield, than PTA fat yield and PTA protein yield in the last five years compared to the overall time period.

Estimates of genetic response for PTA milk, fat, and protein yields were higher for dams of bulls, sires of cows, and dams of cows selection in the last five years than over all years. This shows that there was more opportunity for individuals of superior genetic merit to be the parents of AI males and replacement females. Burnside et al. (1992) also found an increasing trend for milk, fat, and protein for recent years (i.e., 1985 to 1988) compared to a lower over all trend in Italian Holteins.

Weighted and unweighted estimated genetic response for fat and protein percentage on birth year were negative and higher in the recent five years than overall for all selection paths except weighted fat percentage for sires of cows, and unweighted protein percentage for dams of cows (Table 6). As PTA milk, fat, and protein increased, a decline in PTA fat and protein percentage occurred for all four paths of selection. Lee et al. (1985) also reported a similar decreasing trend for fat percentage in Holstein cattle as milk and fat yield increased.

Considering all four selection paths, estimates of genetic response for milk was higher for SB path. Lee et al. (1985) also found larger rates of change for genetic merit of sires than corresponding changes in dams. Extensive selection was for sires of bulls, which gave a higher increase of PTA values over time. Estimated annual genetic change in the Jersey breed by combining all paths of selection are given in Table 7. The realized response from selection, determined by weighted average PTAs for sires of bulls, dams of bulls, sires of cows, and dams of cows, was higher from 1983 to 1987 than over all years from 1960 to 1987 for milk yield, fat yield, protein yield, and fat percentage. Estimates of genetic response by using weighted and unweighted average PTAs were similar for all five traits from 1960 to 1987, however, there were larger differences between these two estimates in the last five years. This indicates that there have been changes in emphasis on different traits. There were better sires and dams available for genetic enhancement of their progeny than those used most frequently in breeding to develop young sires and replacement females. This is shown by the higher estimated response from the unweighted average PTAs for milk yield and fat yield than the eatimate by using the weighted average. The weighted average response in protein protein yield was higher than the unweighted average response in the last five years. This indicates that better sires and dams for protein yield were being used more frequently than all sires and dams available for breed improvement.

Table 7. Overall estimated annual genetic change for milk yield, fat yield, protein yield, and fat and protein percentages.

			Overall	Last five years
Milk	(kg)	Wtd	76.08 ±4.68	137.44 ±36.90
		Unwtd	77.02 ±3.74	201.12 ±23.92
Fat	(kg)	Wtd	2.94 ±0.21	5.96 ± 0.78
		Unwtd	2.96 ±0.16	8.26 ± 1.02
Protein	(kg)	Wtd	2.24 ±0.15	4.06 ± 1.58
		Unwtd	2.50 ±0.12	2.24 ± 0.92
Fat	(%)	Wtd	0.0114±0.0016	0.0128± 0.0193
		Unwtd	-0.0092±0.0010	-0.0054± 0.0080
Protein	(%)	Wtd	0.0160±0.0011	-0.0130± 0.0078
		Unwtd	0.0060±0.0007	-0.0040± 0.005

CONCLUSIONS

Records for young AI bulls and replacement famales of American Jersey dairy cattle from 1960 to 1990 were used in this study to evaluate genetic improvement per year.

There was a nonlinear trend in the generation intervals by year of birth for the parents of young AI bulls. The generation intervals for sires of bulls, increased from 1965 to 1978 and then declined. The generation intervals for dams of bulls increased from 3.9 years in 1965 to 6.2 years in 1970, remained constant from 1970 to 1985, and gradually declined from 1985 to 1990. The generation intervals for sires of cows and dams of cows remained relatively constant from 1965 to 1990. There was a higher average generation interval for sires of bulls than optimum for genetic improvement (Van Tassell and Van Vleck 1991). The average generation for sires of bulls was higher from 1975 to 1984, because of higher use of old proven bulls. The average generation interval for sires of cows and dams of cows were relatively constant over all years, and almost the same as reported by Van Tassell and Van Vleck (1991).

Weighted average selection differentials for sires of bulls for milk and fat yield tended to be higher than the unweighted average. Sires of bulls had higher selection differentials for milk yield than values reported by Miller (1961) and Lytton (1969), but lower selection differentials for fat percentage than reported by Miller (1961). From 1982 to 1986 the selection differentials for milk yield, fat yield, protein yield, and fat percentage, weighted by the number of sons and unweighted, were higher than the overall average.

Average predicted transmitting ability (PTA) for dams of bulls, weighted by number of sons and unweighted, were higher than the average of all cows born in the same year for milk and fat yield. Selection differentials for fat percentages were lower in the last five years than the overall average. The weighted selection differentials for sires of cows for milk yield and fat yield were lower in last five years than the overall average. Average selection differentials for fat and protein percentage were lower in the most recent five years than the overall average, but there was relatively little change over this period.

Estimates of genetic response for milk yield of sires of bulls, and dams of bulls was higher in the last five years than over all years. Genetic response of milk yield was higher for sires of bulls than in other paths of selection.

BIBLIOGRAPHY

Burnside, E. B., and K. Kuersten. 1985. Trends in generation intervals for AI sires. Paper presented at CAAB Sire analysis Conference. Department of Poultry Science and Animal Science, University of Guelph Ontario.

Burnside, E. B., G. B. Tanson, G. Civati, and E. Dadati. 1992. Observed and theoretical genetic trends in a large dairy population under intensive selection. J. Dairy Sci. 75:2242.

Butcher, K. R., and J. E. Legates. 1973. Estimating son's progeny test for milk yield from information on his sire, dam, and maternal grandsire. J. Dairy Sci. 56:675(Abstr).

Butcher, K. R., and J. E. Legates. 1976. Estimating son's progeny test from his pedigree information. J.Dairy Sci. 59:137.

Cassell, B. G., R. E. Pearson, M. L. McGilliard, and T. R. Meinert. 1992. Genetic merit and usage patterns of bulls from different sampling programs. J. Dairy Sci. 75:572.

Dickerson, G. E., and L. N. Hazel. 1944. Effectiveness of selection on progeny performance as a supplement to earlier culling in livestock. J. Agri. Res. 69:459.

Dimitre, A. O., and R. O. Grinberg. 1984. Selection and evaluation of bulls in the Latvian SSR. Anim. Breed. Abst. 52(4):1560. (Abstr.)

Freeman, A. E. 1960. Genetic relationship among the first three lactations of Holstein cows. J. Dairy Sci. 43:876. (Abstr.)

Freeman, A.E. 1974. Choosing and Sampling Young Bulls: Theory, Background, and General problems. In symp. on Choosing and Sampling Dairy Sires. J. Dairy Sci. 58:1063.

Goddard, M.G., and C.Smith. 1990. Optimum number of bull sires in dairy cattle breeding. J. Dairy Sci. 73:1113.

Gruter, O. 1981. Correlations between sires and sons. Animal Breeding Abstract. 51:5420. (Abstr.)

Henderson, C. R. 1964. Selecting the young sire to sample in artificial insemination. J. Dairy Sci. 47:439.

Hillers, J., and A. E. Freeman 1964. Effects of inbreeding and selection in a closed Guernsey herd. J. Dairy Sci. 47:894.

Hinks, C. J. M. 1970. The selection of dairy bulls for artificial insemination. Anim. Prod. 12:569.

Hinks, C. J. M. 1971. The genetic and financial consequences of selection amongst dairy bulls in artificial insemination. Anim. Prod. 13:209.

Hintz, R. L., R. W. Everett, and L. D. Van Vleck. 1978. Estimation of genetic trends from cow and sire evaluations. J. Dairy Sci. 61:607.

Hudson, G. F. S., and L. D. Van Vleck. 1984. Inbreeding of artificially bred dairy cattle in the Northeastern United States. J. Dairy Sci. 67:161.

Hunt, M. S., E. B. Burnside, M. G. Freeman, and J. W. Wilton. 1972. Effects of different artificial insemination stud population sizes on genetic gain when sire sampling and proving programs vary. J. Dairy Sci. 55:716. (Abstr.)

Hunt, M. S., E. B. Burnside, M. G. Freeman, and J. W. Wilton. 1972. Impact of selection, testing, and operational procedures on genetic progress in a progeny testing artificial insemination stud. J. Dairy Sci. 55:829.

Hunt, M. S., E. B. Burnside, M. G. Freeman, and J. W. Wilton. 1974. Genetic gain when sire sampling and proving programs vary in different artificial insemination population sizes. J. Dairy Sci. 57:251.

Jain, J. P., and R. K. Jain. 1981. Rates of genetic improvement under two schemes of progeny testing for crossbreeding herds of various sizes. Indian J. Dairy Sci. 34(4):428.

James, J. W. 1977. Open nucleus breeding systems. Anim. Prod. 24:287.

James, J. W. 1978. Effective population size in open nucleus breeding schemes. Acta. Agri. Scand. 28:387.

Jeon, G. 1986. Prediction of sires transmitting abilities using pedigree information from single and multiple lactations. Unpublished MS. Thesis. Iowa State University, Ames, Iowa.

Kucker, W. L. 1974. Sampling bulls from planned matings in artificial insemination. In symp. on Choosing and Sampling Dairy Sires. J.Dairy Sci. 58:1083.

Lee, K. L., A. E. Freeman, and L. P. Johnson. 1985. Estimation of genetic change in the registered Holstein cattle population. J. Dairy Sci. 68:2629.

Legates, J. E., and R. M. Myers. 1970. Results from young sire sampling. J. Dairy Sci. 53:383. (Abstr.)

Lindhe, B. 1968. Model simulation of AI-breeding within a dual purpose breed of cattle. Acta Agri. Scand. 18:33.

Lohuis, M. M., J. C. M. Deckers, and C. Smith. 1992. Probability of success and predicted returns of sires in progeny test programs. J. Dairy Sci. 75:1660.

Lytton, V. H., R. H. Miller, B. T. McDaniel, and F. N. Dickinson. 1969. Relative selection differentials of sires of A.I. bulls for production traits. J. Dairy Sci. 52:946. (Abstr)

Mao, I. L., A. E. Wilhelm, M. C. Dong, and C. E. Meadows. 1991. Comparison of bull-dam herds, progeny testing herds, and other Dairy Herd Improvement herds. J. Dairy Sci. 74:1413.

McDaniel, B. T., H. D. Norman, and F. N. Dickerson. 1974. Variation in genetic merit of sires of herdmates of first lactation cows. J. Dairy Sci. 57:1234.

McGraw, R. L., K. R. Butcher, and B. T. McDaniel. 1980. Progeny tested sires compared with pedigree selected young sires. J. Dairy Sci. 63:1342.

Meuwissen, T. H. E. 1989. A deterministic model for the optimization of dairy cattle breeding based on BLUP breeding value estimates. Anim. Prod. 49:193.

Miglior, F., B. Szkotnicki, and E. B. Burnside. 1992. Analysis of levels of inbreeding and inbreeding depression in Jersey cattle. J. Dairy Sci. 75:1112.

Miller, R. H., B. T. McDaniel, F. N. Dickerson, and V. H. Lytton. 1967. Selection differentials of sires of bulls used in Dairy Herd Improvement Association herds. J. Dairy Sci. 52:946. (Abstr.)

Murphy, P. A., R. W. Everett, and L. D. Van VlecK. 1982. Comparison of first lactations and all lactations of dams to predict son's milk evaluations. J. Dairy Sci. 65:1999.

Nelson, R. H. and J. L. Lush. 1950. The effects of mild inbreeding on a herd of Holstein-Friesian cattle. J. Dairy Sci. 33:186.

Norman, H. D., and R. L. Powell. 1986. Pedigree selection of dairy bulls in the United States and resultant progeny tests. 3rd World Congress on Genetics Applied to Livestock Production. Lincoln, Nebraska. p196.

Oltenacu, P. A., and C. W. Young. 1974. Genetic and financial considerations of progeny programs in an artificial insemination dairy cattle population. J. Dairy Sci. 57:1245.

Plum, M., and G. A. Myron. 1956. Estimation of genetic gain in milk yield by selection in a closed herd of dairy cattle. J. Genetics. 50:1.

Polyanichko, Y. A. I. 1981. Selection of cows on pedigree and own performance. Anim. Breed. Abstr. 1983 (51):125.

Powell, R.L., and A. E. Freeman. 1974. Estimator of sire merit. J. Dairy Sci. 57: 1228.

Powell, R.L., H. D. Norman, and F. N. Dickinson. 1977. Trends in breeding value and production. J. Dairy Sci. 60:1316.

Rendel, J. M., and A. Robertson. 1950. Estimation of genetic gain in milk yield by selection in a closed herd of dairy cattle. J. Genet. 50:1.

Robertson, A., and J. M. Rendel. 1950. The use of progeny testing with artificial insemination in dairy cattle. J. Genet. 50:21.

Schneeberger, M., A. E. Freeman, and P. J. Berger. 1982. Income and risk for dairymen selecting sires for artificial insemination. J. Dairy Sci. 65:988.

Skjervold, H. 1963. The optimum size of progeny groups and use of young bulls in A.I. breeding. Acta Agri. Scand. 13:131.

Toro, M. A., B. Nielo, and C. Salgado. 1988. A note on minimization of inbreeding in small scale selection programmes. Livestock Prod. Sci. 20:317.

VanRaden, P. M., C. A. Ernst, G. R. Wiggans, and H. D. Norman. 1989. Ability of animal model and modified contemporary comparison evaluations of parents to predict future progeny performance. J. Dairy Sci. 72 (Suppl. 1) : 72.

Van Tassell, C. P., and L. D. Van Vleck. 1991. Estimates of genetic selection differentials and generation intervals for four paths of selection. J. Dairy Sci. 74:1078.

Van Vleck, L. D. 1969. Relative selection efficiency in retrospect of selected young sires. J. Dairy Sci. 52:768.

Van Vleck, L. D., and H. W. Carter. 1972. Comparison of estimated daughter superiority from pedigree records with daughter evaluation. J. Dairy Sci. 55:214.

Van Vleck, L. D. 1982. Theoretical weights for regression of a son's genetic evaluations. J. Dairy Sci. 65:164.

Vinson, W. E., and A. E. Freeman. 1972. Selection of Holstein bulls for future use in artificial insemination. J. Dairy Sci. 55:1621.

Vinson, W. E. 1974. Selection Differentials. In symp. on Choosing and sampling dairy sires. J. Dairy Sci. 58:1071.

White, J. M. 1974. Future needs for better sampling methods. In symp. on Choosing and sampling dairy sires. J. Dairy Sci. 58:1086.

Wiggans, G. R., and P. M. VanRaden. 1989. Developments in the USDA animal model system for genetic evaluation of yield traits. J. Dairy Sci. 71 (Suppl.1) : 71.

ACKNOWLEDGMENTS

I am thankful of Dr. P. J. Berger, my major professor, for guidance in planning and execution of this investigation and for his helpful suggestions in the preparation of this thesis. I am also thankfull to Dr. A. E. Freeman and Dr. D. F. Cox for serving on my graduate committee.

This research was supported by grants from the United States Agency for International Development through the Pakistan Participant Training Program and the American Jersey Cattle Club. I am also thankful for the help from Dr. G. R. Wiggans and United States Department of Agriculture Animal Improvement Program Laboratory for providing the BLUP animal model evaluations for Jersey cattle used in this thesis.

I also thank my officemates, En-Chung Lin, Mahinda Dematawewa, Boulbaba Rekik, and Dr. K. Shimada for discussions and encouragement. My friend, Munwar Ali Memon, helped me solve problems while working on the data.

Extra special appreciation is extended to my elder brother, Rashid Ahmed, for managing my family affairs. To my children, Toufique Ahmed and Tousif Ahmed, my wife, Amna, and my mother, Allah Bachai, for their patience and understanding during my long absence from home. Words can not express my thanks to my late father, Ali Mohammad, who had been the lime light of my life and whose love, affection, encouragement and patience has made this program possible.

APPENDIX: WEIGHTED AND UNWEIGHTED SELECTION DIFFERENTIALS FOR SB, DB, SC, DC.

Table 8. Average weighted selection differential for sires of bulls.

Birth year	Milk	Fat	Protein	Fat	Protein
	kg			%	
1960	346.97	22.76	-1.63	0.1037	0.1069
1961	218.37	8.98	-9.99	-0.0328	0.0483
1962	486.06	15.22	-2.16	-0.1126	0.0040
1963	216.73	10.63	-6.77	-0.0034	0.0882
1964	519.00	12.76	-4.70	-0.0409	0.0328
1965	436.05	15.47	-0.71	-0.0950	0.0256
1966	364.47	11.62	-4.12	-0.1076	-0.0089
1967	266.25	13.51	-5.13	0.0074	0.0333
1968	577.82	20.93	3.48	-0.1127	-0.0234
1969	339.66	15.55	-1.20	-0.0135	0.0190
1970	336.47	11.49	-1.29	-0.0798	0.0084
1971	519.19	13.37	4.50	0.0233	0.0008
1972	584.82	19.47	8.25	-0.0212	-0.0023
1973	502.54	21.15	9.07	-0.0516	-0.0150
1974	492.99	13.17	4.10	0.0494	0.0453
1975	242.20	9.91	2.97	-0.0310	0.0076
1976	300.20	8.29	1.53	-0.0080	0.0043
1977	605.72	29.55	16.08	0.0120	-0.0298
1978	681.98	21.87	16.94	0.0800	0.0265
1979	552.42	29.82	17.52	0.0562	-0.0225
1980	818.12	39.88	26.04	0.0114	-0.0031
1981	248.93	14.59	8.21	0.0477	-0.0113
1982	445.94	20.20	13.33	-0.0114	0.0052
1983	874.30	28.48	24.70	0.1630	0.0788
1984	662.22	25.07	18.64	0.0808	0.0699
1985	876.63	23.51	23.76	0.2572	0.1236
1986	773.28	27.16	19.23	0.1379	0.1490

Table 9. Average unweighted selection differential for sires of bulls.

Birth year	Milk	Fat	Protein	Fat	Protein
	kg			%	
1960	58.23	2.93	-15.52	0.0036	0.0625
1961	66.72	1.91	-15.20	-0.0238	0.0605
1962	57.29	1.04	-15.30	-0.0301	0.0552
1963	51.22	3.25	-13.75	0.0142	0.0781
1964	126.84	4.99	-12.17	-0.0208	0.0420
1965	213.80	7.19	-8.28	-0.0563	0.0391
1966	205.84	8.13	-8.16	-0.0295	0.0331
1967	141.29	6.34	-9.07	-0.0081	0.0513
1968	205.15	9.27	-7.23	-0.0101	0.0246
1969	226.68	10.55	-4.94	-0.0048	0.0364
1970	190.81	8.94	-5.05	-0.0023	0.0284
1971	276.13	9.70	-1.84	-0.0610	-0.0066
1972	230.88	10.03	-1.09	-0.0169	0.0150
1973	269.79	11.35	1.41	-0.0273	0.0032
1974	150.48	8.61	-1.69	0.0250	0.0140
1975	196.39	8.08	0.44	-0.0213	-0.0062
1976	155.27	4.52	-1.64	-0.0518	-0.0245
1977	305.06	14.08	6.94	-0.0067	0.0039
1978	308.88	13.31	6.66	-0.0188	-0.0271
1979	239.31	10.97	6.19	-0.0034	-0.0103
1980	301.76	14.33	9.37	0.0035	-0.0104
1981	223.46	10.89	6.50	0.0084	-0.0166
1982	185.01	10.95	5.05	0.0384	-0.0130
1983	243.55	11.33	6.57	0.0010	0.0110
1984	545.61	21.92	16.97	0.0423	0.0337
1985	557.27	19.70	16.19	0.0915	0.0626
1986	743.46	25.57	18.89	0.1262	0.1273

Table 10. Average weighted selection differential for dams young bulls.

Birth year	Milk	Fat	Protein	Fat	Protein
	kg			%	
1960	149.81	7.60	-11.42	0.0045	0.0698
1961	160.40	6.68	-11.48	-0.0220	0.0586
1962	203.62	8.72	-9.59	-0.0227	0.0527
1963	213.87	9.94	-8.21	-0.0097	0.0603
1964	217.97	10.29	-8.05	-0.0056	0.0531
1965	228.32	9.94	-7.53	-0.0213	0.0401
1966	255.40	9.29	-6.17	-0.0560	0.0361
1967	267.86	11.34	-4.64	-0.0303	0.0408
1968	276.99	12.38	-3.62	-0.0186	0.0410
1969	246.19	11.02	-3.24	-0.0166	0.0386
1970	340.56	12.79	-0.10	-0.0630	0.0083
1971	268.43	9.56	-1.50	-0.0588	-0.0016
1972	330.15	13.49	1.97	-0.0407	-0.0061
1973	280.82	11.74	2.17	-0.0303	0.0067
1974	282.75	12.06	3.32	-0.0241	0.0046
1975	282.12	11.68	4.13	-0.0307	0.0012
1976	249.24	10.51	4.24	-0.0242	-0.0020
1977	230.96	10.20	4.14	-0.0140	-0.0028
1978	297.48	11.71	6.81	-0.0372	-0.0246
1979	254.29	10.20	6.65	-0.0291	-0.0129
1980	381.94	16.37	11.34	-0.0228	-0.0223
1981	370.11	14.66	11.45	0.0111	-0.0100
1982	323.59	12.45	10.17	0.0171	-0.0125
1983	378.00	17.05	12.28	-0.0064	0.0069
1984	522.02	21.11	16.64	0.0390	0.0242
1985	467.04	19.73	14.74	0.0303	0.0396
1986	567.16	25.37	18.68	0.0015	0.0336
1987	539.33	22.83	18.08	-0.0002	0.0241

Table 11. Average unweighted selection differential for dams young bulls.

Birth year	Milk	Fat	Protein	Fat	Protein
	--------------kg--------------			--------%--------	
1960	134.77	6.51	-12.06	0.0009	0.0715
1961	141.58	5.97	-12.15	-0.0153	0.0643
1962	192.14	8.49	-9.95	-0.0146	0.0581
1963	186.48	8.72	-9.29	-0.0048	0.0632
1964	187.19	8.90	-9.04	-0.0018	0.0597
1965	207.20	8.99	-8.21	-0.0179	0.0462
1966	226.46	8.41	-6.90	-0.0459	0.0457
1967	247.31	10.64	-5.20	-0.0228	0.0473
1968	250.16	10.75	-4.49	-0.0224	0.0475
1969	218.57	9.78	-4.09	-0.0133	0.0460
1970	277.89	10.23	-2.12	-0.0548	0.0152
1971	247.43	8.99	-2.00	-0.0514	0.0051
1972	268.69	10.40	-0.00	-0.0427	-0.0023
1973	244.73	9.81	0.75	-0.0331	0.0069
1974	237.79	9.87	1.62	-0.0253	0.0065
1975	232.87	9.58	2.51	-0.0261	0.0077
1976	216.35	9.08	3.29	-0.0210	0.0039
1977	188.63	8.25	2.84	-0.0118	0.0014
1978	256.51	9.83	5.62	-0.0382	-0.0183
1979	219.33	8.99	5.48	-0.0222	-0.0098
1980	287.23	12.38	8.58	-0.0202	-0.0157
1981	299.95	11.93	9.50	0.0028	-0.0202
1982	287.95	10.91	8.89	0.0159	-0.0124
1983	349.85	15.00	11.30	0.0054	0.0081
1984	451.32	18.53	14.53	0.0292	0.0191
1985	430.09	18.48	13.73	0.0239	0.0365
1986	525.22	22.79	17.64	0.0112	0.0278
1987	521.35	21.81	17.39	0.0025	0.0255

Table 12. Average weighted selection differential for sires of cows.

Birth year	Milk	Fat	Protein	Fat	Protein
	kg			%	
1960	197.24	12.00	-8.91	0.0400	0.0812
1961	180.34	6.14	-11.59	-0.0497	0.0463
1962	230.91	5.82	-10.08	-0.0970	0.0306
1963	178.22	8.84	-8.22	0.0009	0.0885
1964	433.48	10.87	-6.10	-0.0784	0.0127
1965	318.90	11.11	-4.50	-0.0765	0.0337
1966	316.13	9.73	-5.31	-0.0986	0.0078
1967	258.55	11.43	-5.63	-0.0215	0.0309
1968	491.72	18.16	1.34	-0.0936	-0.0146
1969	411.20	18.58	2.09	-0.0235	0.0209
1970	365.30	12.32	-0.43	-0.0910	-0.0011
1971	470.93	12.04	3.26	0.0073	-0.0072
1972	463.76	15.67	5.08	-0.0514	-0.0244
1973	480.83	21.25	8.22	-0.0334	-0.0180
1974	402.59	14.18	3.75	-0.0388	-0.0110
1975	282.19	12.31	4.19	-0.0190	0.0036
1976	268.65	11.20	2.86	-0.0257	-0.0294
1977	479.48	23.42	12.46	0.0104	-0.0158
1978	516.39	18.85	12.42	0.0078	0.0031
1979	430.79	23.00	13.09	0.0392	-0.0201
1980	509.32	24.59	15.83	0.0060	-0.0179
1981	244.70	9.83	6.09	-0.0064	-0.0015
1982	295.96	11.71	7.65	0.0099	0.0088
1983	468.41	16.57	13.62	0.0617	0.0321
1984	204.47	9.73	6.31	0.0021	0.0016
1985	242.50	10.77	7.60	0.0028	0.0180
1986	368.45	16.68	10.73	-0.0102	0.0448
1987	321.48	15.31	10.78	0.0003	0.0146

Table 13. Average unweighted selection differential for sires of cows.

Birth year	Milk	Fat	Protein	Fat	Protein
	kg			%	
1960	21.37	1.01	-16.75	-0.0001	0.0659
1961	20.92	0.69	-16.66	-0.0056	0.0674
1962	16.11	0.42	-16.27	-0.0062	0.0653
1963	32.27	1.56	-14.95	0.0004	0.0700
1964	47.70	1.85	-14.27	-0.0084	0.0683
1965	55.39	2.49	-13.02	-0.0029	0.0609
1966	80.92	3.39	-11.84	-0.0082	0.0537
1967	35.72	2.11	-12.43	0.0072	0.0621
1968	84.01	4.30	-10.07	0.0057	0.0566
1969	84.11	4.43	-8.83	0.0073	0.0546
1970	120.25	5.12	-7.31	-0.0107	0.0305
1971	160.61	5.74	-4.86	-0.0346	0.0127
1972	112.56	4.24	-4.85	-0.0200	0.0189
1973	120.44	5.40	-3.05	-0.0065	0.0225
1974	112.68	5.67	-2.38	0.0054	0.0194
1975	112.03	4.11	-2.12	-0.0210	0.0053
1976	105.18	3.79	-1.59	-0.0209	-0.0043
1977	126.45	4.42	0.04	-0.0270	-0.0079
1978	137.44	5.04	1.20	-0.0252	-0.0158
1979	100.11	4.29	1.10	-0.0071	-0.0088
1980	109.80	4.50	2.06	-0.0114	0.0916
1981	125.71	4.62	2.55	-0.0125	-0.0175
1982	150.35	5.08	3.44	0.0052	-0.0088
1983	170.04	6.32	4.77	0.0091	0.0004
1984	141.95	6.33	4.47	-0.0055	-0.0040
1985	134.63	7.31	4.69	0.0186	0.0014
1986	240.48	11.19	7.39	-0.0027	0.0255
1987	284.10	13.07	9.39	-0.0031	0.0171

Table 14. Average weighted selection differential for dams cows.

Birth year	Milk	Fat	Protein	Fat	Protein
	-------------	kg	-------------	-------- %	--------
1960	22.42	1.08	-15.71	-0.0032	0.0659
1961	24.99	1.16	-15.19	-0.0040	0.0649
1962	26.93	1.19	-14.68	-0.0052	0.0650
1963	25.96	1.16	-14.29	-0.0048	0.0626
1964	26.10	1.22	-13.64	-0.0036	0.0624
1965	34.18	1.47	-12.84	-0.0061	0.0581
1966	36.38	1.49	-12.18	-0.0075	0.0545
1967	37.23	1.68	-11.76	-0.0049	0.0553
1968	38.38	1.80	-10.90	-0.0038	0.0535
1969	43.91	1.90	-9.57	-0.0065	0.0477
1970	44.93	1.67	-8.62	-0.0111	0.0404
1971	37.17	1.49	-7.63	-0.0069	0.0322
1972	37.40	1.52	-6.46	-0.0064	0.0278
1973	38.71	1.52	-5.47	-0.0075	0.0234
1974	42.04	1.55	-4.53	-0.0095	0.0186
1975	34.62	1.47	-3.95	-0.0046	0.0172
1976	33.08	1.45	-2.93	-0.0034	0.0138
1977	37.76	1.60	-2.05	-0.0045	0.0097
1978	36.54	1.48	-1.16	-0.0053	0.0050
1979	37.83	1.52	-0.44	-0.0052	0.0020
1980	41.35	1.76	0.35	-0.0040	-0.0010
1981	38.00	1.52	0.67	-0.0050	-0.0022
1982	36.28	1.43	0.79	-0.0048	-0.0025
1983	37.64	1.52	1.03	-0.0043	-0.0028
1984	34.22	1.35	1.04	-0.0045	-0.0025
1985	26.18	1.00	0.83	-0.0011	-0.0013
1986	25.52	1.01	0.88	-0.0035	0.0022
1987	22.79	0.90	0.84	-0.0035	-0.0007

Table 15. Average unweighted selection differential for dams cows.

Birth year	Milk	Fat	Protein	Fat	Protein
		kg		%	
1960	11.27	0.56	-16.10	0.0003	0.0704
1961	10.55	0.50	-15.77	-0.0002	0.0699
1962	11.81	0.52	-15.29	-0.0010	0.0690
1963	10.02	0.45	-14.85	-0.0006	0.0674
1964	9.45	0.48	-14.24	0.0005	0.0670
1965	15.45	0.64	-13.51	-0.0020	0.0624
1966	17.57	0.70	-12.79	-0.0027	0.0591
1967	19.10	0.83	-12.36	-0.0018	0.0593
1968	17.61	0.77	-11.61	-0.0014	0.0580
1969	22.81	1.00	-10.23	-0.0019	0.0525
1970	22.53	0.80	-9.32	-0.0052	0.0456
1971	17.45	0.73	-8.15	-0.0018	0.0372
1972	16.45	0.70	-7.02	-0.0015	0.0331
1973	18.88	0.71	-6.07	-0.0034	0.0273
1974	20.09	0.73	-5.17	-0.0043	0.0231
1975	16.03	0.68	-4.53	-0.0015	0.0210
1976	14.67	0.64	-3.51	-0.0010	0.0177
1977	18.68	0.80	-2.66	-0.0015	0.0134
1978	17.83	0.71	-1.77	-0.0023	0.0082
1979	20.59	0.81	-1.03	-0.0028	0.0047
1980	21.18	0.89	-0.31	-0.0018	0.0021
1981	20.61	0.81	0.07	-0.0029	0.0001
1982	22.69	0.86	0.33	-0.0035	-0.0007
1983	24.15	0.99	0.60	-0.0024	-0.0010
1984	23.97	0.95	0.71	-0.0030	-0.0015
1985	18.64	0.72	0.60	-0.0023	-0.0008
1986	22.58	0.89	0.78	-0.0029	0.0024
1987	22.81	0.91	0.84	-0.0029	-0.0008